



This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

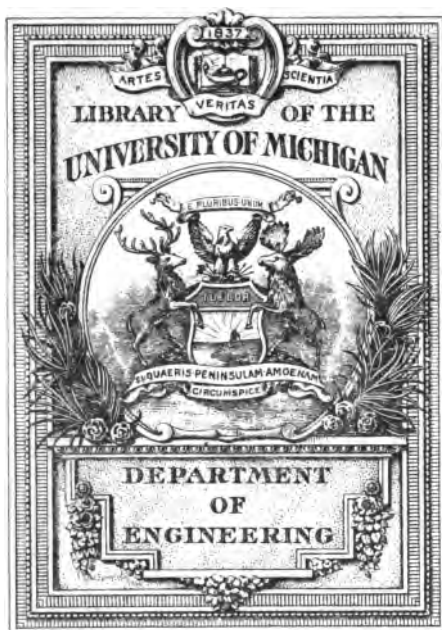
Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

- + *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
- + *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
- + *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
- + *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at <http://books.google.com/>



ENGINEERING
LIBRARY

TA
195
.N373

The D. Van Nostrand Company

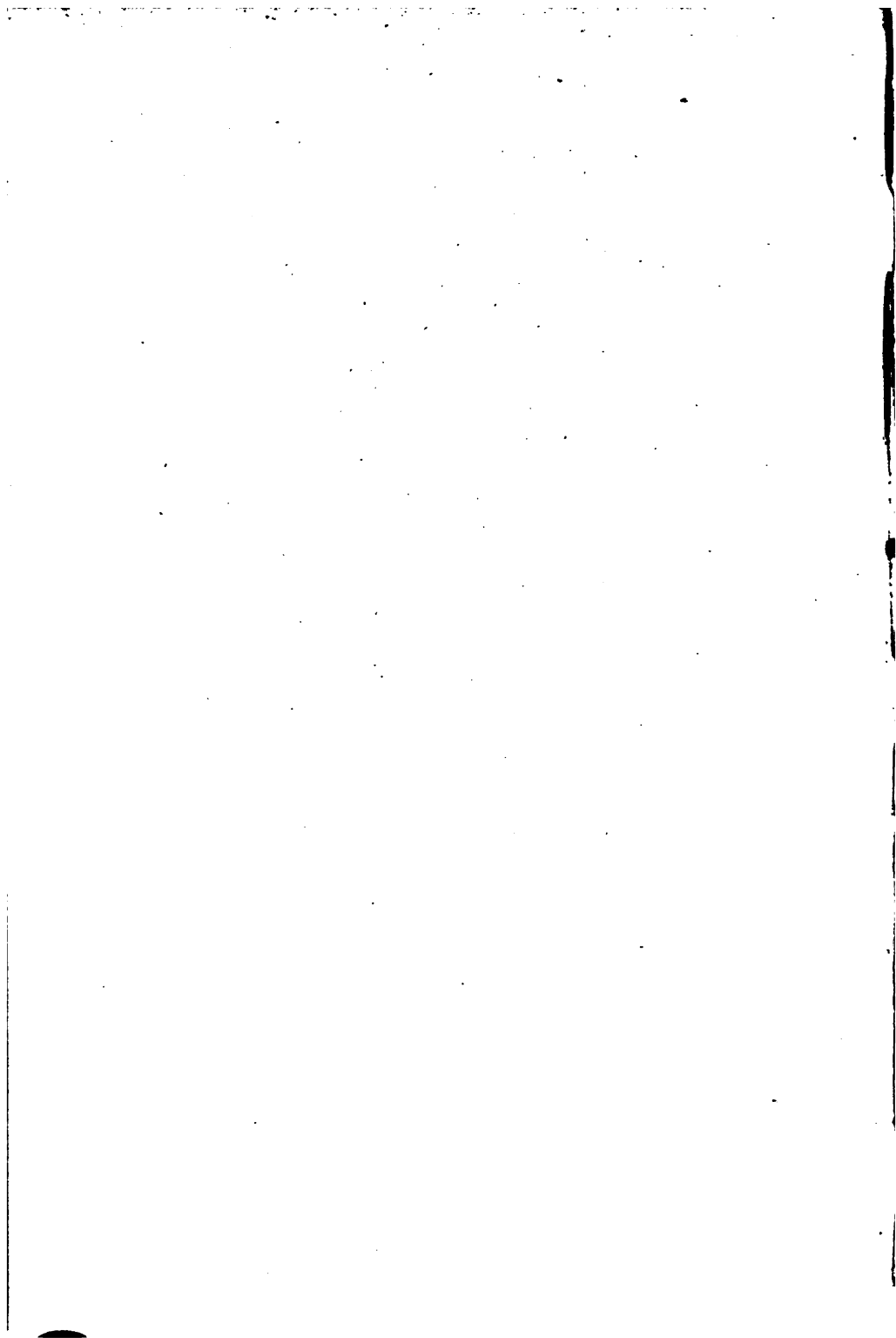
intend this book to be sold to the Public
at the advertised price, and supply it to
the Trade on terms which will not allow
of reduction.



ENGINEERING
LIBRARY

TA
195
.N373

**ENGINEERING WORKSHOP
MACHINES AND PROCESSES**



ENGINEERING WORKSHOP MACHINES AND PROCESSES

*A HANDBOOK FOR THE USE OF STUDENTS AND
OTHERS TAKING THE WORKSHOP TRAINING
RECOMMENDED BY THE INSTITUTION
OF CIVIL ENGINEERS*

BY
DIPL-ING. F. ZUR NEDDEN

TRANSLATED AND REVISED BY
JOHN A. DAVENPORT, M.Sc.(VICT.), ETC.
LONDON UNIVERSITY MATRICULATION EXAMINER

WITH AN INTRODUCTION BY
SIR ALEX. B. W. KENNEDY, LL.D., F.R.S., ETC.

AND CONTAINING, BY PERMISSION, A REPORT ON
THE EDUCATION AND TRAINING OF ENGINEERS
ADOPTED BY THE COUNCIL OF THE INSTITU-
TION OF CIVIL ENGINEERS



NEW YORK
D. VAN NOSTRAND COMPANY
23 MURRAY AND 27 WARREN STREETS
1910

4-14-41 3
①

TRANSLATOR'S PREFACE.

THE report of the Committee appointed by the Institution of Civil Engineers to consider the best methods of training and educating engineers contains the following sentence : " The Committee reaffirm the conviction expressed when they issued their inquiry, that the sympathetic assistance of employers is essential to improvement in engineering education and training " (p. 194).

Recd in 5-14-41 MJS

In Germany, the employers co-operate with the men responsible for the technical training of engineers, and there is a well organised and definite scheme whereby the young men spend one year in the workshop before proceeding to the University or High School ; this twelve months' practical work is called the " Practical year," and the young men taking it are known as " Volunteers." The German edition of this book was written to assist the volunteers during their practical year, and contains four parts divided into fourteen chapters ; of these, Parts I. and II., containing eight chapters, deal chiefly with the works co-operating in the scheme, the choice of works, rights and duties of volunteers, organisation, administration, etc., and are therefore unsuited to the present English requirements ; the remainder is given in Chapters I. and II. of this volume, but altered to suit the needs of English

readers. Chapters IX. to XIV. of the German are translated, with practically no change, as Chapters III. to VIII. of the present volume.

I take this opportunity of thanking Sir Alex. B. W. Kennedy for his interest and suggestions; Dr. F. J. Brislee for reading through the proofs; the Council of the Institution of Civil Engineers for permission to include the report on "The Education and Training of Engineers"; Messrs. W. H. Allen, Son & Co., Ltd., for the subject-matter of Chapter II.; and Messrs. Smith & Coventry, Ltd., for revising the greater number of the figures given in the tables on pages 153—4.

JOHN A. DAVENPORT.

LIVERPOOL,

December, 1909.

The author in his preface says: "The numbers given in the text are not to be taken as strictly accurate, but only as relatively accurate; in fact the book must be regarded as just a little more than a 'Popular description' of the subject." In this connection I should like to point out that the temperatures are given in 'Round numbers' Centigrade with the corresponding Fahrenheit temperatures.

INTRODUCTION

THE student who, having said good-bye to school or college, finds himself for the first time free from "pastors and masters," and at liberty to devote his whole time to the "practical" work which he has been for so long anxious to commence, is perhaps in a little danger of forgetting that he is still only at the beginning of his training. In spite of the sessions which he has spent listening to lectures, in spite even of the hours spent in laboratory work, in spite of the fact that he really has (or may have) learnt a great deal about the scientific side of his future profession, he has in reality to start on a new alphabet when he makes a start on works or in shops. His previous training will have made it easy for him to learn the new alphabet, but all the same it remains an alphabet which has to be learnt. And the learning has to be done without the help of professors or teachers, and to a large extent without that of books.

A few years ago the leading professional societies* formed a committee, under the presidency of Sir

* The societies represented on the committee were:—The Institution of Civil Engineers, the Institution of Mechanical Engineers, the Institution of Electrical Engineers, the Institution of Naval Architects, the Iron and Steel Institute, the Institution of Gas Engineers, the Institution of Engineers and Shipbuilders in Scotland, the Institution of Mining Engineers, and the North-East Coast Institution of Engineers and Shipbuilders.

William White, for the purpose of considering the question of the best general lines on which the training of engineers of different kinds should be carried out. After long and very careful deliberation, the committee unanimously issued a report which, by the courtesy of the Institution of Civil Engineers, is reproduced as an appendix to Mr. zur Nedden's book on pages 173-207 below. So far as English engineering students are concerned, it may be taken that this book is designed to assist them at the outset of a professional career undertaken in accordance with the recommendations of the committee.

The duties of an engineer may be said to be of two kinds—the designing of work, and the carrying out of the work designed. The work itself may be either in the nature of a machine or a structure, or it may often be some general combination of machines or structures, such as a power house or a railway. But the man who has to design the combination should first have become familiar with the design of the details. Similarly, the carrying out of the work may be either the construction of a machine or the erection of a structure, or the connection and putting to work of a complicated system of plant. But here also the man who has to superintend the more complex duties ought first to have become personally familiar with the simpler ones.

Equally for the design of a steam engine and for that of a breakwater, a foundation of mathematical and physical knowledge is required—a knowledge of the actions of the natural forces which help us and which fight against us, a knowledge of the properties

of the materials which we have to employ, a knowledge of the way in which those particular materials can be best dealt with in order to serve our purposes. A considerable part of this knowledge can be obtained in colleges or technical schools, which nowadays do much more than mere lectures and bookwork, by giving their students not only opportunities for practical observation and measurement of the properties of constructive materials, but also personal experience in the experimental working out of actual problems connected with the economy and efficiency of boilers, prime movers, machine tools, and so on.

It is now fully recognised by all engineers that such a course of scientific training is a proper and necessary preliminary to professional work. It is recognised also, as fully, and set forth in the report above referred to, that the scientific training must be completed by some years of practical work in workshops and offices, or on works. It has always been sufficiently obvious that where a man intended to become a manufacturer he must have preliminary training in a workshop. But the committee went so far as to express the opinion that even where the ultimate object of the engineer was to take up the design of structures as far removed from workshop practice as, say, docks or breakwaters, it was still desirable on general grounds that (wherever circumstances rendered it possible), before or after the theoretical training, but preferably before it, the young man should spend a year in some mechanical workshop in daily contact with the workmen and in daily handling

of ordinary commercial tools and appliances in course of being used for actual commercial work.

It is chiefly with a view to help young engineers at this stage that Mr. zur Nedden's book has been written and translated. Its intention is to set out in a condensed but intelligible form those matters which a young engineer entering shops for the first time will find frequently to be taken as data—assumed as being known already by those who are around him in the shops, to whom all such matters are so familiar that they seem hardly worth while telling. With some of them he may already have made himself familiar in lectures. Many others will not have come within the scope of college teaching at all. Here it has been attempted to summarise the whole.

Mr. zur Nedden emphasises strongly, in the introduction to the original edition of his work, that the commercial side of design is equally important with its scientific side, and that although the commercial side—a side which is concerned with £ s. d., and therefore with the livelihood of the engineer—can no more be taught in a book than in lectures, it is possible in a book which is to be used in connection with everyday shop experience to point out to the student the considerations which will chiefly affect matters from this point of view, and show him how best he may direct his attention to them. Mr. zur Nedden further points out that in many cases the cost of any engine or machine depends even more upon the cost of machining, that is to say upon the cost of transforming it from the condition of raw material to the finished state, than

upon the cost of the material itself. The designer has not only to produce a machine which shall do the work which it is intended to do, and to see that it is made of the right materials, but further to devise its construction in such fashion that it may be completed into its final shape with a minimum of expense. This is only possible when the designer is thoroughly familiar with the whole of the working processes of an ordinary shop. He can only make practicable and economical designs when he is conversant with the "tricks" of the shops, the special machines used in them, and the particular manner of their use. It is not necessary for the designer to be extremely proficient himself in either hand work or the use of machine tools, but he must be able from his own experience to know how both ought to be used and to estimate the advantages and disadvantages of each. He must personally know how the total of the work is subdivided, and how the appliances in a workshop can be best arranged to suit the necessary subdivision. He must know from experience what work is difficult and what is easy, and how much ability and brains each class of work requires from the workmen. It is necessary for him to pay attention to the cost of the various materials, and still more to the cost of the processes which they undergo in the shop, with a view to obtaining later on a knowledge of the costs in wages, machine tool charges and establishment charges for any new work. It is necessary for him also to know the considerations which govern the shapes which can conveniently and economically be given to finished

pieces of different materials, so that he may instinctively give to steel parts shapes which can be most easily dealt with in steel, to castings those shapes which can most conveniently be reproduced in cast iron or gun-metal, and so on. Last, but certainly not least important, he must in the shops study and try to understand the workman upon whose skill and quickness in dealing with the appliances put at his disposal the success of any industrial undertaking so largely depends.

Mr. zur Nedden concludes his introduction by saying "It is the many-sidedness of the practical work of the young engineer which, after due cultivation, builds up the 'engineering instinct' without which no engineer can be successful. Workshop experience necessitates observation, reflection, ability, tact and hard work, and the engineer's success later in life will depend greatly upon the exercise of these faculties in his workshop years."

I think the observations of the author which I have summarised in the last few paragraphs are very just and wise, and I am glad to believe that this book, in its English dress, is likely to be of great use to the young engineer and to help him in directions in which up to now he has had very little outside assistance.

ALEXANDER B. W. KENNEDY.

September, 1909.

TABLE OF CONTENTS

CHAP.	PAGE
I. GENERAL REMARKS	1
Efficiency of Engines and Machines, Effect of Workmanship and Design upon the Efficiency, Use of Drawings, Sketching.	
II. THE MODERN ENGINEERING WORKS	10
III. MATERIALS OF CONSTRUCTION	14
A. Raw Material :	
Elasticity, Change of Shape, Elastic Limit, Ultimate Strength, Ductility and Brittleness, Hardness, Work- ing of the Material, Cutting, Forging, Casting.	
Iron : Iron Ores, Blast Furnace Process, Reduction, Blast, Fluxes, Arrangement of Blast Furnace, Pig Iron, Blast Furnace Gas, Slag, Effect of Carbon.	
Foundry Pig Irons : Silicon and Manganese, Grey Pig, White Pig, Iron Founding.	
Refined Pig Irons : Silicon, Sulphur, Phosphorus, Wrought Iron, Reduction of Percentage Carbon.	
Refining Process.	
Puddling Process.	
Steel Manufacture : Bessemer Process, Thomas Process, Siemens-Martin Process, Cementation Process, Special Steels.	
Table of Properties of Iron in Relation to the Contained Carbon.	
Copper : Copper Alloys, Brass, Bronze, Phosphor Bronze, Delta Metal, Aluminium Bronze.	
Alloys of Tin.	
Cost of Raw Material, Estimation of Weight, Average Prices of Metals, Table of Strengths, &c., of Metals, Remarks on the Choice of Materials.	

CHAP.	PAGE
B. Manufactured Iron : Rolling, Drawing, Pressing, Special Productions, Finished Fittings, Screws, Pipes, Lubricators.	
IV. FOUNDRY AND PATTERN SHOP	64
Making the Mould, Division of Mould and Pattern, Moulding Sands, Moulding Boxes, Cores, Prints, Fitting Strips, Striking Boards, Moulding Machines, Melting, Casting, Wasters, Separation of Gas, Contraction, Dressing.	
Observation Hints.	
V. FORGING	88
A. The Smithy : Handwork, Welding, Welding Power, Special Welding Processes, Die Forgings, Power Hammers, Presses.	
B. Boiler Shop: Riveting, Riveting Machines, Marking-off, Various Machines, Constructional Ironwork.	
C. Tool Smithy and Hardening : Object of Hardening, Theory of Hardening, Temperatures, Annealing, Cooling, Hardening Fluids, Testing Hardness, Tempering, Working with One Heat, Machining Hardened Steel, Case Hardening.	
Observation Hints.	
VI. THE MACHINE SHOP	113
A. General: Setting, Jigs for Setting, High Speed, Cooling, Cutting Capacity, High Speed Steel, Tool Grinding, Turnings and Borings, Practicable Shapes, Working of Machines, Erection, Accuracy.	
B. Types of Machines: Review, Table of Machines Classified according to their Motions :	
1. The Lathe : Turning, Screw-cutting, Boring, Facing, Special Lathes, Turret Lathes, Automatic Machines.	
2. Boring and Turning Mills.	
3. Planing and Slotting Machines: Planing or Milling ?	
4. Milling Machines: Milling Cutters, Cylindrical and End Milling Cutters, Formed or Profile Milling Cutters, Backed-off Cutters, Circular Milling.	

TABLE OF CONTENTS

xv

CHAP.	PAGE
5. Drilling Machines : Drilling and Facing, Reamering, Arrangement of Holes, Drilling Jigs, Types of Drilling Machines.	
6. Grinding Machines : Method of Working, Emery Wheels, Wet Grinding.	
Observation Hints	
Tables Giving Important Particulars of Machine Tools.	
VII. MEASURING AND MARKING-OFF	155
Degrees of Accuracy, Measuring, Plug and Ring Gauges, End Gauges, Caliper Gauges, Limit Gauges, Screw Gauges, Tool Room, Marking-off.	
Observation Hints.	
VIII. FITTING, ERECTING AND TESTING	164
Value of Handwork.	
Rigid Fastenings : Cold Riveting, Shrinking-on, Solder- ing, Solders, Pressing.	
Removable or Temporary Fastenings : Screws, Keys, Jointing or Packing, Grinding-in, Scraping.	
Testing.	
Observation Hints.	
APPENDIX. THE EDUCATION AND TRAINING OF ENGINEERS	173
INDEX	209

ENGINEERING WORKSHOP MACHINES AND PROCESSES

CHAPTER I

GENERAL REMARKS

THE engineering workshop is chiefly employed in the manufacture of engines, machines (wood-working, metal-working, brickmaking, chaff-cutting, etc., etc.), and constructional iron and steel work; and we may divide these into two distinct classes. In the first, in which we include engines and machines, the important characteristic of every example is the relative motion of different parts of the whole; in the second, which includes constructional iron and steel work of all kinds, this relative motion of the parts is absent. The consequences of the relative motion of the parts in the first class are of great importance to the engineer, and for this reason some introductory remarks are given in this chapter. The remainder of the chapter contains general remarks, but dealing chiefly with metals and drawings, two things which are of importance in the manufacture of both classes of work.

An engine is used to convert natural energy, such as that contained in gas, steam, etc., into mechanical energy; while a machine utilises the mechanical energy from the engine in doing useful work of some

2 WORKSHOP MACHINES AND PROCESSES

kind, such as the drilling of holes, planing, turning, milling, etc. The connection between the two, in virtue of which the energy is conducted from the engine to the machine, is known as power transmission; the principal methods being by means of belts, wheels, and shafts. Referring to engines and machines as machines simply, there is one point of greatest importance to the engineer. The machine receives a certain amount of energy, and delivers a smaller amount, converted into some particular form. In the conversion of energy from one form to another, there is always a loss, and as energy has to be paid for, this means a loss of money. This loss is unavoidable, being due to the rubbing of the parts together, air resistances, changes of shape in the materials used, and any vibration. The aim of the engineer is to reduce it to a minimum, to which end he continually observes the amount of energy given to any machine, and the amount of energy delivered by it. In order that all machines may be compared, the latter amount is divided by the former, and the quotient is called the "efficiency" of the machine, and is denoted by the Greek letter η . Suppose, for example, that an engine delivers 100 units of mechanical energy for 1,000 given to it, then the efficiency is 0.1. Another engine might deliver 1,000 units of mechanical energy for 10,000 units of natural energy given to it; here again the efficiency is 0.1. The capacities of the engines are different, but they are equally efficient, each giving out $\frac{1}{10}$ th of the energy given to it, as useful mechanical energy. The efficiency of an engine may be anything from 0.05 to 0.4, while a machine tool may have $\eta = 0.8$ to 0.9.

As already mentioned, loss of efficiency means loss

of money, and for this reason it is the duty of the engineer to keep η as high as possible. In order to do this he must know what things tend to reduce the efficiency, and how each affect it. Now, generally speaking, the efficiency of any machine (in the general sense) depends upon two important things, the conditions under which the natural store of energy is used, and mechanical conditions. The former refers to the condition of the steam or gas used, and must be left for the study of the university or technical school. The latter refers to the condition of the machine itself as turned out from the works, and depends chiefly upon the design and the workmanship.

The design is the particular work of the designer or draughtsman. He must design the various parts separately, and then scheme the general connections and arrangements, putting the whole work in the form of a drawing for the use of the workmen. To do this he must have a knowledge of the forces acting upon the whole machine and the separate parts, and know the strengths of the different materials used in the manufacture of machines. He can then design the work so that the strength of any section is greater than the force it has to withstand, and is thus strong enough to resist breakage.

The workmanship may be put under three heads, machining, fitting, and erection, and is carried out in the various shops devoted to these branches. It is the duty of the shop foreman to divide the work so that it may be done economically and well; great attention being paid to accuracy, as inaccuracy may cause a great loss of energy due to friction.

The metals used in engineering work are to be distinguished chiefly for their inappreciable changes in

4 WORKSHOP MACHINES AND PROCESSES

shape when acted upon by forces. For this reason wood is not found in machines, but only such metals as iron, steel, copper, bronze, and some zinc alloys. The choice of the metal for any part depends upon (1) strength, (2) ease of manufacture, (3) price, and (4) resistance to rubbing on other metals. All metals do not fulfil the requirements in the same way, so that the choice is given to that which has the greatest number of desired qualities. For intricate shapes, cast iron is chosen, especially when joints can be avoided, as they are more or less costly to prepare. It is sometimes replaced by a steel casting, made from a more recently introduced metal than cast iron. Small castings which have not to resist great forces such as cocks, valves, and the like, are made of brass and bronze, because this metal is easier to cast than cast iron, being more thinly fluid when molten; it cannot be used for large work on account of its cost.

The casting is made by pouring molten metal into a "mould," already prepared by means of a "pattern." As the pattern is costly, requiring skilled labour in its making, the process is only economical when it can be used many times.

Cast iron is exceedingly brittle, and for this reason cannot be used in some cases, being replaced by wrought iron and steel. The parts made from these metals, known as "forgings," have to be forged when hot, and consequently cannot be made to take the intricate shapes given to cast iron. If the forging is incomplete when the metal is cold, it must be given another "heat," i.e., heated again, during which heating there is a loss of metal by oxidation. A repetition of this injuriously affects the quality of

the metal, and is to be avoided; therefore comparatively simple shapes are to be adopted for forgings. The smithy and foundry, with which might be taken the pattern shop, are the shops in which the raw material or rough parts are made. When at work in these shops the young man should learn to distinguish castings from forgings and cast metal from forged metal, by the outside appearance. Forged metal, such as wrought iron and steel, can be much better distinguished by the appearance of the fracture than the outside layer, and this should be noted.

The casting or forging is taken to the machine shop, where, after being marked off, the necessary machining is done. It is then taken to the fitting shop for the necessary hand work, and then to the erecting shop for erection into the finished machine. The amount of work necessary in the making of joints, where two parts are to be fitted together, should be noticed, as this gives a reason for the making of parts as large as possible. If two parts can be made in one piece, the cost is much reduced; and as the compound part will be more intricate than either of the single, it will probably be easier to make of cast iron than wrought iron.

Any saving in cost of joint making and the like must be put against any extra cost of pattern, the most economical result being adopted. The size of such parts is limited by the convenience of manufacture and transport.

Attention should be paid to the various parts as they arrive in the erecting shop ready for erection. The methods and appliances of this shop, with the various forms of bolts, keys, feathers, rivets, etc., are instructive. Then the completed machine is tested before being delivered; a work of great importance, not only to the

6 WORKSHOP MACHINES AND PROCESSES

firm, but also to the young engineer. Finally, the machine is packed up and sent away to its destination ; and in this packing great care must be exercised, in order that no damage shall be done in transport and that the machine can be correctly erected on delivery. Thus the machine is of interest to the engineer from the time of its conception to its being put to work ; and the processes are to be closely watched and studied as indicated more particularly in the following chapters.

From the first day of his practical experience onwards, the young man will observe the importance of mechanical drawings. In each shop the drawings or "prints" are referred to for direction many times a day, and thus the brain of the designer works for the whole of a well organised works. The drawing is the key to everything, showing the whole and each part of the machine, as it is to be finished ; but in such a way that the reading of it is more or less difficult. Thus the question arises whether the young man should be assisted in the matter by the foreman, or left to himself. It would be a good plan for the foreman to give an occasional hint and leave his charge to study the subject in an evening class, or to read a good book on the subject. In any case, the young man is warned not to spend too much time on the drawing, as he does not go into the workshop for that alone. It will be sufficient if he learns to read a drawing so that he can follow it in machining some part.

The drawing must precede the manufacture of the machine, and therefore cannot be produced by photography as in the case of illustrations for catalogues. It must be a true representation of the various parts, showing everything to scale. It must make possible the jointing together of the various parts ; and,

according to the law of economy, this must be done in the simplest manner.

Keeping these things in view, the first step towards the correct understanding of mechanical drawing is made. It is now clear why one looks in vain for any picturesque effect in a mechanical drawing. The draughtsman confines himself to circles and straight lines, which, being set down of certain lengths, make up together the part he wishes to represent.

The representation of a body in this way is only complete when considered from three points of view, *i.e.*, all particulars are to be seen if the body be viewed from the front, side, and above. In this way three "views" or "projections" are obtained, and they are combined on the one drawing, or sheet. At first sight it may appear that this method is not as simple as perspective; but as perspective distorts the shape it is not applicable to scale drawings.

In order to read the drawing correctly a knowledge of the method of arranging the views is necessary, and this is to be learnt from some standard text book on the subject. For intricate work it will be found that three views are not sufficient; and as designing consists in the making of sections, such sections must be represented on the drawing. This is generally the case, and therefore sections will be found in the greater number of drawings. Now, as a section represents the inside, while the simple view represents the outside, some means must be adopted to distinguish one from the other. In coloured drawings this is done by colouring the section with some shade suitable to the metal it represents, while the outside is left without colour. Such colours are: cast iron, grey; steel, purple; bronze, yellow, etc. If the drawing be

uncoloured the sections are cross-shaded or cross-hatched, *i.e.*, diagonal lines, close together, are drawn across, while the outside is left without lines.

The various lines in a coloured drawing are to be distinguished by various colours, such as centre lines, red; dimension lines, blue. In an uncoloured drawing they are: centre lines, dot and dash — - — - —; dimension lines, dash, dash, — — — —; while a line made of dots - - - - - represents some line in the part which is hidden in the particular view. It is not the practice to send the drawings into the shops, as they would soon become covered with dirt from the men's hands. To obviate this difficulty the drawing is traced, and from the tracing one or more blue prints are taken by means of photography. They are usually of white lines on a blue background, and being considered uncoloured, will have the lines and sections as indicated above.

Each drawing should be accompanied by any notes referring to the amount or method of machining necessary, together with a list of parts. There should be no ambiguity about these notes, and their arrangement will distinguish the good from the bad designer.

The theoretical training in mechanical drawing should be done in the evening while the young man is doing his practical work. It will be found that greatest progress is made in this way, because he has the advantage of referring to the actual parts of any machine on the morning following his lesson.

While engaged in the study of drawing, time should be spent in freehand sketching, first from the object and then from memory. It is surprising how little one knows of a machine one has worked on, say, for six months, till one tries to sketch it from memory. The

sketch may slightly resemble the part, but the proportion will be altogether wrong. This is the key to the whole thing—proportion. Anybody can sketch a house, but how many can sketch a house that has fair proportions? Thus the freehand sketching of parts from memory will bring out any defective knowledge or ideas, and go a long way towards the general training.

CHAPTER II

THE MODERN ENGINEERING WORKS

As an example of the general arrangement in the present day first-class practice, a ground plan and description of the works of Messrs. W. H. Allen, Son, & Co. Ltd., of Bedford, are given in fig. 1. The works, which are of moderate size, employing about 1,100 men, are engaged in the manufacture of high class machinery, comprising high speed engines, with and without dynamos, centrifugal pumps, air pumps, surface and jet condensers, fans, air compressors, high-lift turbine pumps, oil engines, and auxiliary machinery for the Admiralty. The site occupies 10 acres, on the western side of the main line of the Midland Railway, upon four acres of which the workshops are built. The remaining six acres are for storage and future extensions. It will be noticed from the ground plan that the railway siding runs throughout the whole length of the works. This, together with the 5 and 10 ton derricks shown makes the loading and unloading of material easy and economical. The raw material, from which the machinery is completely manufactured in the works, is taken from the railway trucks and thence to the various stores; wood to the wood stores, pig-iron to the foundry stores, wrought iron and steel to the smithy stores, and coke to the coke bins.

As the wood is required it is taken from the stores to the pattern shops, where by means of up-to-date wood working machinery, it is made into patterns.

Pattern Swires

Tom
Eric

Mat

Wor

The pattern is taken to the foundry where it is used to make the mould, and after use there it is taken to the pattern stores. It will be noticed that the pattern shop and foundry are adjacent, such arrangement being necessary on account of the intercourse between the two. The pig-iron and coke are taken from their respective stores to the foundry in which are two cupolas, one of 15 tons and the other 10 tons capacity per hour. A special arrangement is in use on the charging floor, by means of which the analysis and weight of the charge are accurately determined. The molten metal is taken from the cupolas to the moulds, in ladles which are carried by four electric overhead travellers. Three of these are of 5 tons capacity, while the fourth is of 15 tons capacity, and they run the whole length of the foundry. There are, in addition, slewing jib cranes, operated by hand, arranged on alternate columns.

The brass foundry, which can turn out a casting up to 30 cwt. in weight, is provided with six pot furnaces, and one large air furnace. All castings, especially those which have internal core work, are treated carefully with acid, outside the building, thus ensuring that the sand is completely removed.

The wrought iron and steel are taken from the smithy stores to the smithy in which are three large hammers, the largest being of one ton capacity. There are various other machine tools in this department, which, together with the blowers, are electrically driven. The castings and forgings are taken to the distributing bay, which, it will be seen, adjoins the various departments of the machine shop on one side, and the foundry on the other.

It is served by an overhead traveller and a set of

12 WORKSHOP MACHINES AND PROCESSES'

floor rails for trucks. The work is distributed to the various departments in this bay, or, by its connection with the siding, the finished machine work may be taken and put directly into railway trucks.

The work passes through the various machine shops, being transported by means of electric overhead traveling cranes, three of 10 tons capacity and one of 15 tons capacity. After machining it is taken to the erecting shop for erection, and then passes on to the adjacent testing department.

The testing department is well equipped and is divided into four branches, viz., the Admiralty testing department; department for central station equipment, including engines, dynamos, and condensing plants; the pump department; and that for auxiliary machines and motors. In the Admiralty testing department the complete generating plant for a first-class battleship or cruiser can be tested simultaneously, while in the central station department an engine of 1,500 horsepower can be tested.

After being tested the work is taken to the painting and packing shop where it is prepared for delivery.

All machines run at a high speed and use the "A.W." brand of high speed steel, which, together with the fact that the limit gauge and drill block systems are used, explain the important area and position of the tool room as seen on the plan. Another important department is the examiner's department attached to the machine shop. Here a complete system of examination is carried on, all machined work being sent to the examination table to be thoroughly checked. The whole of the works is driven by electricity which is taken from the generating station. When the steam boilers were first put down, some

difficulty was experienced owing to the hardness of the water, but this has since been overcome by the addition of water purifiers. The cooling pond on the plan is for cooling condensing water used in the testing department.

The company have for several years taken great interest in the training of pupils and in the social life of the workmen. For the former there is a special department, which includes the lecture room, shown, in charge of a demonstrator. For the latter an institute, shown on the plan, has been built, in which the men may pass their leisure time in an agreeable manner.

CHAPTER III

MATERIALS OF CONSTRUCTION

A. Raw Material.

THE present-day engineer must be just as familiar with the properties and characteristics of the materials of construction, as a doctor is with the human body; and to this end he builds up, exclusively, on knowledge which is scientifically obtained. This experimental knowledge is acquired in the laboratory of the university or technical school.

The pure mathematical treatment of the subject cannot be wholly set aside, nor yet be allowed to stand alone; but to the engineer who thinks, it will be a most valuable aid. He first of all deals with the mathematical part, and uses this as a guide in his final treatment of the subject, which is governed by his "engineering instinct." This has its basis in his knowledge of the behaviour of the material when being prepared, and when at work in the machine; and as this knowledge has to be acquired at first hand by direct observation, it will be readily seen that the practical work of the engineer is a most important part of his training.

The engineer directs his observations chiefly to two things:—

1. To the strength properties.
2. To the working properties.

The scientific bases of these properties are naturally physics and chemistry; but the engineer's knowledge exceeds the bounds of these sciences, and becomes

practically a special science in itself, built up by many years of scientific research and workshop experience. A large number of the more important observations, which have to be made with scientific instruments and methods, will be referred to. In this connection we have, in the first place, the strength properties and their dependence upon the chemical structure of the metals.

Elasticity.—The man in the street regards a piece of metal merely as something strong enough to support the load it carries, not knowing that when it is acted upon by forces, it exhibits exactly the same elastic properties as a piece of india-rubber. In the mind of the engineer, however, a piece of metal acts exactly the same as a piece of india-rubber, except that the magnitudes of the deformations are different. These are, in the case of metals, measurable, although not apparent to the naked eye; and it is therefore exceedingly important for the engineer to learn, at the outset, the visible differences in the behaviour of the metals as an aid to the judgment of their strength properties.

Change of shape.—The fundamental property of all bodies is their yielding to applied forces. If we suspend an iron rod from the ceiling, and hang a weight to the lower end, the rod tends to follow the pull of the weight; but as its upper end is fixed it merely becomes longer. At the same time, the force due to the applied weight is transmitted to the fastening, which likewise undergoes a smaller deformation. An anvil is compressed when struck with a hammer, although the deformation is not apparent to the naked eye. It transmits the pressure to the block upon which it rests, which is likewise deformed, in just the same way as a piece of india-rubber would be if we placed it under

another piece and pressed on the upper. These changes, which are apparent in the case of india-rubber, are reproduced when we use iron and steel, only on a very much smaller scale.

Such changes or deformations are known as extensions or reductions in length of the body; and always accompany the application of forces. But in the case of a plastic material, such as lead, the elongation remains, to a smaller extent, even when the force is removed. This is also true of other materials when, by reason of the large force applied, they are rendered plastic.

Elastic limit.—On the other hand there are bodies, which, for repeated applications of the same force, have practically the same change of shape; and this is the same no matter how often the load is applied and taken away. Each time the load or force is taken away the bar takes up its original length again, provided the force does not exceed a certain value, which depends upon the material. This, so to speak, springy property of the body is called elasticity, and for this reason the value referred to above is called the “elastic limit,” and is quoted as so many tons or pounds per square inch.

Ultimate strength.—The physical explanation of these phenomena is that the molecules of the body, *i.e.*, the very small particles of which the body is built up, are held together by cohesion forces. As an illustration we may consider the body to be built up of a number of very small particles which are bound to one another by rubber bands. When a pull or push force is applied to the body the rubber bands yield until the united effect of their individual pulls or pushes is equal to the force applied; but should the applied force exceed the whole of these little cohesion

forces, the body remains lengthened, even when the force is removed, and the material is said to be "plastic." It has received what we call a "permanent set"; and this permanent set always accompanies a force which exceeds the elastic limit. Should the applied force go on increasing, it will reach a point at which the connections between the particles are destroyed, and the body is fractured. The force which produces fracture in a body depends upon the size and shape of the piece dealt with, and in order that results obtained experimentally by different people may be comparable, they must be obtained from pieces of standard size, which standards are determined by the engineering institutions. The experiments to determine the force to produce fracture are carried out in "testing machines" upon standard "test pieces," and the results are known as "ultimate strengths" of the various materials, in tension or compression. They form the most important foundation for the work of the designer.

Ductility and brittleness.—While the test piece is in the testing machine, we may, if we have the apparatus, measure the different changes in length for different loadings (forces), and finally, the amount of elongation a bar is capable of before being fractured. It will be found that the final elongation is different for different materials, and that the body which alters most is not necessarily the weakest. It is well known that there is a vast difference between the strength of a sword blade and a cane, in spite of the fact that they may be equally flexible. In this observation our judgment must be guided by the "ductility" or the "brittleness" of the material. A brittle material is not in the condition to withstand successfully the destroying

influence of a suddenly applied load, on account of the fact, that it is not capable of a change of shape. It is therefore easily broken by blows or shocks. On the other hand, a ductile material yields to a blow, thereby lessening the effect of the shock, and after the impact is deformed but not broken. It is clear that this property of ductility is a most desirable one from the point of view of the designer. His calculation is quite sufficient for the general run of forces; but an accidental shock may always appear, and as this cannot be foreseen and calculated, he must depend largely upon the ductility of the material.

Hardness.—The strength properties considered up to this point refer to the behaviour of the body as a whole, when acted upon by external forces. But the resistance of the surface of a body to penetration by scratching or cutting is no less important. We speak of the “hardness” or “softness” of a body, but it is not so easy to define a scale for the degrees of hardness. It cannot be measured in tons per square inch as in the case of the ultimate strength; still we may adopt the physical “hardness scale,” or “scale of hardness,” which has for its basis the fact that one body is harder than another when it can cut or scratch it. The hardness scale consists of a number of standard materials, and they are arranged in such a way that, taking any one, it will scratch all below it in position, but none above it. This kind of estimation is most important for the working of machine parts in the workshop, as it will tell us whether one piece of steel will cut another, or not. But for the use of finished machine parts another measure of hardness is important, namely, the “wearing out scale,” so to speak. We know that the rubbing of two neighbouring

parts upon one another plays an important part in the design of machinery. The harder both are, the longer they will last, till an appreciable amount of wear, due to the rubbing, becomes the result. We can therefore put a greater load upon two hard bodies which rub together, than upon two soft bodies, and this without fear of "seizing," *i.e.*, without fear of the surfaces being bound together owing to intense pressure.

Both measures of hardness, the scratch proof and the wearing away proof, have only been established by long experiment, to which work we are indebted for the testing standards and numerical values.

Working of the Material.

Cutting.—We have already seen, in dealing with the scale of hardness, that in their normal conditions metals may have small pieces cut from them. The mechanical workshop offers a large field of observation which will enable the young engineer to estimate the desirability of such processes being adopted.

Forging.—A further important property of metals can be dealt with, when we take account of a factor which, up to this point, has been neglected ; namely, the temperature. Generally speaking, an increase in the temperature of a metal means a decrease in strength and a lowering of the elastic limit. On this account we can easily give to hot metal a permanent shape by means of pressing, hammering, drawing, or rolling. This property of malleability is possessed by many metals in the cold state, more especially iron and steel ; but to work them cold involves very great pressures, which can only be attained by heavy and costly machinery. So that the cost will be much reduced if the metal is forged at a glowing heat ; as then the

work necessary to produce a change of shape is much less than in the cold state.

Casting.—If we carry the heating to extremes, the cohesive forces between the molecules become completely removed, *i.e.*, the metal is fluid. In this state it offers no resistance to change of shape, and can be fashioned in any desired way by pouring into moulds. There are different kinds of metal suitable for casting, and their properties are not all alike. The important points to be noted are: the temperature necessary to attain the required degree of fluidity; the liberation of gas on solidifying; the contraction of the metal on cooling; and the strength in the cold state. All these facts have to be considered in the production of castings.

This short review of the knowledge of the strength and mechanical properties puts us in position of understanding the relation between them and the chemical nature of the materials. The progressing knowledge of this connection enables us to produce metals which have the various properties we desire most; as present-day metallurgists can accomplish many things in accordance with the engineer's demands. As an example of this collaboration of the engineer and metallurgist, we have the high speed tool steel of to-day. The consideration of these refinements must be left to the study at the university or technical school.

The following are a few of the fundamental facts, briefly considered.

Iron. Specific gravity 7·6—7·8.

The material which the Engineer calls iron is never chemically pure iron, but a mixture of iron and other elements, of which the chief are: carbon, manganese,

silicon, sulphur, and phosphorus. Different mixtures of these constituents produce iron of widely different properties. In fact, an alteration in the amount of only one of the ingredients is responsible for a large difference between the properties of the iron. For example, the difference between iron and steel depends solely upon the amount of carbon.

Iron ores.—Iron is obtained from iron ores, which may be arranged in two groups: (a) ores containing oxygen; (b) ores containing sulphur. For the manufacture of iron, only the ores containing oxygen are directly applicable to smelting, as sulphur ruins iron. But the ores containing sulphur (pyrites) are used for the manufacture of sulphuric acid, from which process there remains as a residue an oxide of iron, which can be smelted in the same way as the ores containing oxygen. These ores with oxygen are as follows:—

1. Magnetite, or magnetic iron ore ($\text{Fe}_3 \text{O}_4$), which is mined in a crystalline state. It is the richest iron ore, containing, when pure, as much as 72·4 per cent. of metal. It is found in large quantities in Sweden, in parts of North America, and in India.

2. Red iron ore, or red hæmatite ($\text{Fe}_2 \text{O}_3$), occurs in radiating masses, made up of layers with smooth kidney-shaped surfaces. It is particularly free from phosphorus, and on this account iron which has less than 0·1 per cent. of phosphorus is known as hæmatite iron. It is found in Canada, the United States, India, Spain, and in England in Cumberland and Gloucestershire.

3. Brown ironstone, or brown hæmatite ($\text{Fe}_2 \text{O}_3 \cdot \text{H}_2 \text{O}$) is a hydrated oxide of iron and varies in colour from bright yellow, through brown, to almost black; but all have a brown or yellow streak. It contains from 27 to

63 per cent. of iron, and is of extreme importance to the iron industry, on account of the readiness with which it can be mined, and the ease with which it can be reduced in the furnace. It is found in Germany, in the lakes of Sweden and Canada, from which it is dredged, and in England in Cornwall, Northamptonshire, Lincolnshire and Oxfordshire.

4. Spathic iron ore (Fe CO_3) occurs in the crystalline form, and again as "clay ironstone" mixed with clayey matter. The iron varies from 30 per cent. to 49 per cent., while it contains from 0.25 to 0.75 per cent. of phosphorus. It is found in Styria, Germany, Lanark in Scotland (blackband ironstone), and in England in Staffordshire, Yorkshire, Cleveland, and, to a small extent, in South Wales.

In some cases the iron ore can be treated at once in the blast furnace without any preliminary preparation; but this is not always permissible. When preliminary work is necessary it must, on account of the comparatively low value of the metal, be of a cheap and simple character. The ore is hand-picked to separate pyrites and earthy bodies which are associated with it, and is then "sized," *i.e.*, it is broken to pieces of the required size, necessary to make the subsequent operations regular. After this it is "calcined" (heated in order to drive off volatile matter) in open heaps or in kilns, by which means water, carbon dioxide, and sulphur are eliminated and the bulk of the ore reduced. It is then ready for the "reduction process" in the blast furnace, this being the name given to the process of removing the oxygen from combination with the iron.

Reduction.—This process is simple in principle, the ore containing oxygen being brought into intimate contact with carbon (in the form of coke or coal) at a white

heat. At the high temperature, carbon possesses a great affinity for oxygen, and they combine in the furnace, escaping in the form of gas, and leave iron behind.

The blast furnace process depends, for complete success, upon several important factors, as follows:—

Blast.—The high temperature in the furnace can only be produced and maintained by supplying to the fire a sufficient quantity of oxygen, and this is done by blowing air into the furnace. The air is blown in under a pressure of from 4 to 10 lbs. per square inch, which is necessary for it to penetrate the dense mass of ore and coke in the furnace. After being dried by refrigeration, it is heated to a temperature of from 600° to 900° Centigrade (1,112 to 1,652 Fahrenheit), as a cold blast would reduce the heat in the furnace. The oxygen combines with the carbon on its way up through the furnace and escapes from the top as combustible “blast furnace gas.” It is not allowed to escape to the atmosphere, but is led away through pipes to the air-heating stoves and to steam boilers, where it is burnt. In this way the large heating power of the gas is utilised, not only to heat the blast, but to drive engines which produce the necessary air pressure for the blast.* The weight of gas passing out at the top of the furnace is, roughly, three times the weight of iron and slag passing out at the bottom of the furnace.

Fluxes.—As the iron descends in the furnace, is freed from oxygen and becomes fluid, there is a risk of it oxidising again owing to its contact with the rising air blast. To prevent this a flux is used which consists usually of limestone, which forms a slag consisting chiefly of silica, lime, and alumina. At the high temperature of the furnace the slag is fluid and surrounds

* See also p. 27.

the small particles of iron in their descent, thus protecting them from oxidation by the blast. The iron and slag, both fluid, sink to the bottom of the furnace, and form two layers, the slag uppermost, on account of its lower specific gravity. In this way the fluid iron, which is ready to be drawn from the furnace, is further protected from the oxidising influence of the blast by the layer of fluid slag. A further duty of the flux is to render the stony constituents of the ore more easily fluid, as otherwise they would become packed into a dense mass which would stop the working of the furnace after a short time.

The blast furnace charge is made up of four parts :—

1. Ore containing oxygen.
2. Carbon in the form of coke. Coke is preferable to coal, as the coal, at the great heat, is liable to be pressed into cakes which prevent the free passage of the air.
3. Air for the blast.
4. Fluxing material.

Process in the furnace.—The mixture of ore, coke, and flux is prepared to have the requisite chemical constituents, and is charged into the cup at the top of the furnace, the cone being closed to the cup meanwhile, to prevent the escape of gas. The cup is then lowered to allow the charge to pass into the furnace, while, at the same time, gas escapes to the atmosphere, and burns with a large flame. The charge falls into the top part of the furnace in which it is gradually heated, and through the continual melting of the material beneath, it travels downward. The reduction takes place at a white heat, being confined first to the surface of the material heated. Owing to the heat and the pressure of the material above, small particles of iron are freed from the mass, and at this instant, as we saw previously,

the fluid slag forms a covering for them. The reduction would not be complete but for the precautions taken by the smelter. Just before the ore melts it is porous, and the flux is arranged so that it melts after the ore is porous, but before it melts. Then the following process goes on without interruption. While the slag is solid and the ore porous, the upward stream of gas, which is rich in carbon monoxide, combines with the oxygen of the ore forming iron and carbon dioxide. The gas rises to the next layer, to the carbon of which it gives one half of its oxygen, and therefore becomes carbon monoxide again. At the same time carbon monoxide is formed from the carbon and the liberated oxygen. The carbon monoxide thus formed rises, and on passing through the next layer of material, which is iron ore, takes up oxygen and becomes carbon dioxide again. This process goes on till the gas reaches the top of the furnace where it has the following composition: nitrogen 59 per cent., carbon monoxide (CO) 25 per cent., carbon dioxide (CO₂) 12 per cent., hydrogen and marsh gas 4 per cent.

The iron ore descends throughout the reduction, and, after the slag is melted, it also becomes fluid and runs down into the hearth below the twyers. It is tapped from time to time through the "iron notch," the lower of the two holes at the bottom of the furnace; while the slag is drawn off through the "slag notch" at the higher level.

Arrangement of the blast furnace.—Fig. 2 shows the arrangement of the blast furnace, which consists of a cylindrical tower from 60 to 90 feet high, and having a capacity of from 20,000 to 50,000 cubic feet. The casing is built of sheet iron and is lined with firebrick, the inside tapering towards the top and bottom. At

the bottom are to be seen two holes, the lower the "iron notch," the upper the "slag notch." A little above the slag notch three or more "twyers," or blast pipes, are placed round the circumference, and they are water-jacketed to prevent them melting. At the top of the furnace is a gallery from which the charges

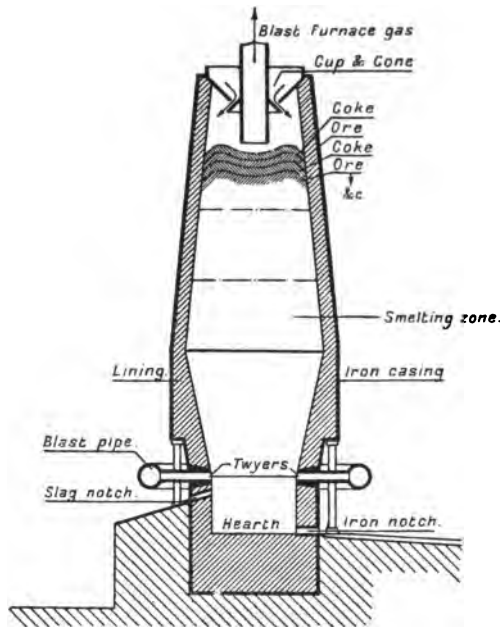


FIG. 2.—Blast Furnace.

are put into the "cup and cone" by means of which the furnace gases are prevented escaping. The cup and cone also plays an important part in the mixing and distribution of the charge in the furnace. The lower part of the furnace gets smaller in diameter as it approaches the hearth, and this is designed to relieve the fluid mass of the great weight of the charge above.

Pig-iron.—The molten iron, on leaving the furnace, is run into a canal of semi-circular section and decreasing area called the sow, to which is connected a number of small cross canals called pigs, and so large that the metal necessary to fill each weighs about one hundred-weight. When cold, the iron in the pigs is broken from the main canal and the bars obtained are known as pig-iron. The iron is also cast mechanically in groups, which are more uniform in size than the older form of pig; when cold they are broken by hydraulic machinery and shot into railway wagons ready for transport. This arrangement is preferable to hand breaking, as it saves labour and assists in classifying the iron.

Blast furnace gas.—The gas which leaves at the top of the furnace, is used, as stated, to heat the blast in Cowper stoves, and to fire the boilers necessary to produce the steam for the blowing engines. Latterly, this process has been carried out without boilers by using the gas directly in gas-blowing engines. After the production of heat and pressure for the blast there may be gas remaining which is sufficient to generate electricity for the whole of the furnace district.

Slag.—The weight of slag produced is about 50 per cent. greater than the weight of iron, and the utilisation of it is therefore an important problem. There have been many experiments to determine the best way of disposal, and as a result there are several methods employed.

1. The harder varieties are often used for road metal, especially where suitable stone is not easily procurable.

2. Bricks are made by casting slag in iron moulds, but they are liable to crack owing to internal forces.

3. The slag is granulated by allowing it to trickle slowly into water. When granulated it is either mixed with lime and pressed into bricks, or it is ground to a powder and used for cement.

4. The molten slag is blown by a jet of steam which produces small globules to each of which is attached a long thin filament. The filaments are separated from the globules by mechanical means and are deposited as "slag wool," a non-conducting non-inflammable packing.

Pig-iron is used in two ways :—

1. For the manufacture of foundry or cast iron.

2. For the manufacture of wrought iron and steel.

Effect of carbon.—Pig-iron contains, on account of the method of production, up to 5 per cent. of carbon. Steel contains at the most, 1·5 per cent. carbon. Wrought-iron is practically pure iron, containing from 0·05 per cent. to 0·5 per cent. of carbon. Iron without any carbon is not met with in practice; it is so soft that it may be cut with a penknife. As the nature of the material depends upon the amount of carbon, so also will the strength properties. Hardness increases with carbon, while ductility increases with decrease of carbon. Cast-iron is hard and brittle, wrought-iron is soft and ductile. Further, the amount of carbon has a great influence upon the temperature of the melting point. It falls as the carbon increases, about 100° Centigrade (180° Fahrenheit) for every 1 per cent. change in carbon. Wrought-iron melts at a temperature of from 1,500° to 1,600° Centigrade (2,732° to 2,912° Fahrenheit), pig-iron at from 1,200° to 1,300° Centigrade (2,192° to 2,372° Fahrenheit). It will thus be seen that, by regulating the amount of carbon (which cannot be substituted by any other element) in

the iron, we may, to a large extent, produce a metal having any properties we choose. This explains the great importance of iron to the engineer.

Foundry Pig-irons.

These are divided into two classes, according to colour, and are known as "grey pig" and "white pig." When iron containing carbon is in the fluid condition, the composition is uniform throughout, the carbon having no tendency to separate from the metal. When the iron is cooled to the temperature at which it begins to solidify it may either retain the carbon, and solidify in a homogeneous form, called white iron, or it may, in solidifying, precipitate the greater part of the carbon in the form of small scales of graphite, which produce the dark colour characteristic of grey iron.

Silicon and manganese.—The reason of these phenomena is explained by the chemists. On analysis, iron is found to contain silicon and manganese in addition to carbon; manganese always being found in white iron, and silicon always in grey iron. Manganese combines with carbon much more strongly than does silicon, and on this account the carbon in the iron containing manganese cannot separate mechanically, but must remain chemically combined, and white iron is produced; but if the iron contains silicon, the carbon may separate mechanically and grey iron be produced.

White or grey iron may be artificially produced by regulating the temperature, and mixing ferro-manganese (iron containing up to 80 per cent. of manganese), or ferro-silicon (iron containing up to 30 per cent. silicon) with the pig.

Grey pig-iron.—Grey pig-iron is specially suitable for all castings which have to be machined. According as

the percentage silicon increases, the chemically combined carbon decreases, and, as previously noted, the lower the percentage carbon chemically combined, the more malleable is the iron. Grey pig when broken has a fracture of a colour varying from light grey to dark grey; the lighter shades of which approach more nearly to the properties of white pig. They are to be distinguished from the dark greys, on account of the thin layer of white iron which is formed on the surface when quickly cooled. This layer has a large percentage of carbon chemically combined which has not had time to separate mechanically, owing to the short time allowed for cooling. The iron thus gets a surface which is very hard and difficult to work, a fact which is taken advantage of for the production of chilled castings.

Dark grey pig-iron contains much more carbon, chemically combined, than the hardest steel; still the large percentage of uncombined carbon renders it more suitable for machining. It is mixed with light grey iron when the hardening effect due to chilling is not desired, as the moulds, which are more or less moist, have a chilling effect upon the iron at all times. This is the reason for the great demand for Scotch dark grey pig-iron No. 1, which, alone, is of little use on account of its brittleness.

White pig-iron.—White pig-iron may be free from silicon, when it crystallises, and is known as “spiegeleisen”; it is used in the manufacture of Bessemer steel. If it contains a small percentage of silicon, the crystals disappear, the iron becoming uniformly close and granular known as manganese iron. It has a great tendency to form holes (blowholes) in the metal, owing to the liberation of gas. If white iron be heated with oxidised ore

or hammer slag (obtained during the manufacture of wrought-iron), carbon is transferred from the iron to the enveloping ore. The chemically combined carbon only changes in this way, part of the whole remaining mechanically mixed as graphite. Castings made from the iron prepared in this way are very brittle, and are perfectly white when fractured. But if they are "annealed" by heating in air-tight boxes filled with hæmatite ore, the heating and cooling taking about three days, they become "malleable castings." The metal has a grey fracture, is soft enough to be readily worked with a file or chisel, and so malleable that it may be bent or hammered out, without fracture. When half the carbon is chemically combined, and the rest remains as graphite, the fracture of the metal has dark grey portions in a matrix of white, and is known as mottled iron. It is not as brittle as the light grey pig, while it is much stronger. When cast in moist moulds, the heat is quickly drawn from the metal which thus gets a very hard surface for about one centimetre in thickness. It is used for rollers for iron rolling mills, firebars, etc.

Iron-founding.—The art of the iron-founder exists in the choice of suitable pig-irons necessary to produce a mixture that shall have the desired properties. To the acquirement of this knowledge he has been aided by the experience of the engineer, and by his own research; and to-day, although the iron-founder can manufacture many different kinds of iron, research is still being carried out, tending to a greater knowledge on the subject of cast-iron. The position now is such that the iron known by names such as Scotch, Middlesborough, etc., is to be represented according to its chemical composition, and the names denoting

different grades, such as silicon iron, grey, middle grey, dark grey, fine grain, coarse grain, etc., are to be replaced by exact numerical values. As the old style of nomenclature is likely to persist for some time, it will be necessary to make use of it, in order to follow the laws of the men who have already investigated the subject.

Refined Pig-irons.

Cast-iron cannot lay great claims to ductility and strength, so that it is not of extreme importance that all other elements should be completely eliminated. But in the case of refined iron, from which wrought-iron is obtained, it is necessary to pay great attention to the removal of all injurious elements. These are :—

Silicon.—Silicon is, in general, not found in many kinds of pig-iron in large percentages. Provided the percentage silicon does not exceed 1·25, the iron may be used in the production of wrought-iron and steel. If the percentage be greater than this, the time required for production is relatively long, and the metal produced is brittle. Iron containing silicon has a dark grey fracture.

Sulphur.—Sulphur makes the iron “red short,” *i.e.*, it is very brittle when at a red heat. It comes from the ore from which the iron is made, or from the coke used in the blast furnace. If the ore contains sulphur, it may be removed by the manufacture of sulphuric acid, already mentioned, and the use of the iron oxide remaining eliminates the risk of sulphur in the pig-iron. The transfer of sulphur from coke to the iron may be avoided by the use of coke which is free from sulphur. To accomplish this, most smelting works manufacture the coke necessary for use in the furnace

in coke ovens, and obtain, in addition to coke free from sulphur, gas which may be used in the same way as the blast furnace gas. Iron containing sulphur has a dull grey fracture.

Phosphorus.—Phosphorus renders cast-iron extremely thin fluid and homogeneous, but “cold short,” *i.e.*, it is very brittle when cold. It is difficult to remove, and, until the introduction of the Thomas process, iron containing phosphorus could not be used in the manufacture of wrought-iron. It has a bright silver white fracture.

Wrought-iron.—Wrought-iron must be particularly ductile, in order to withstand the changes of shape due to the forces which act upon it. If in the form of a bar, it can be bent back upon itself without any sign of fracture, the surface only being rougher than before bending. If in the form of thin bands or wires, it may be tied into knots without fracture. When fractured it resembles, more or less, the fracture of wood, because it has a similar grain. The grain arises from the manufacture of the iron in which it is rolled, the various constituents of the metal being rolled into strings or streaks. This accounts for the statement that “iron is stronger with, than against the grain.” If, in the rolling, some iron with a larger percentage of carbon be accidentally or intentionally added, the iron becomes brittle, and the fracture is said to be crystalline. The smaller the percentage carbon the more ductile the iron, the elastic limit and ultimate strength decreasing at the same time. This puts a lower limit to the percentage carbon, and for commercial iron there should not be less than one half per cent.

Reduction of percentage carbon.—Previously the carbon was reduced in percentage by treating small quantities

of iron in a refining or running-out fire, and this process gave, to the pig-iron used, the name of refinery pig.

The principle of refining is simple. The carbon in the iron has a great chemical affinity for oxygen, and they must be brought together in such a way that they combine without burning the iron. This is done by heating together a mixture of iron and hammer-slag, the oxygen in the slag combining with the carbon in the iron, leaving molten iron below and fluid slag above, which are tapped at intervals. There are two ways in practice of carrying out this process :—

1. The refining process.
2. The puddling process.

Refining Process.

If there be no hammer-slag ready for use, as obtained in the hammering of wrought-iron, it must be prepared by heating the iron in the refining furnace, and blowing air over the surface till it is burnt to the oxide, "hammer-slag." This is heated along with the iron to be refined, when the carbon combines with the oxygen of the slag, as explained. But a certain amount of the iron combines with the oxygen also, the loss of iron due to this cause amounting to 10 per cent. The iron is separated from the slag in very much the same way as butter is separated from butter-milk. The balls of metal so taken from the furnace are first compressed to expel the slag ; this operation being performed by "helves," "squeezers," or steam hammers. It is then rolled into bars in the "puddle rolls," and is known as "puddled iron." The puddled bar is cut into lengths, "piled" (made up into bundles), reheated and rolled again. This process of piling, reheating, and rolling, improves the quality of the iron, provided that it is

not carried too far, six times being about the maximum number permissible without damaging the metal. The result is wrought-iron, and it is given the names "best," "best best," "treble best," according as the piling and reheating has been of small, medium, or large amount.

Refining, as carried out in the refining furnace, produces first-class iron of high value, but it is expensive. Iron which is completely free from silicon can only be used, and the best wood charcoal must be employed for the necessary carbon. On this account, the puddling process was first introduced in England at the end of the eighteenth century.

Puddling.

The furnace is first charged with sufficient flux, or hammer-slag, which has been squeezed out under the hammer from previous balls, and the charge is completed by adding pig-iron. The door is closed and the temperature raised to melt the charge, the best results being obtained when the iron and slag become pasty and melt down together. When the iron is completely fluid, it is watched till a number of small blue jets of flame issue from the surface. The damper is then closed, to lower the temperature somewhat, while the mass is constantly stirred to prevent the iron settling to the bottom, and to assist in removing the carbon, by bringing the iron and slag into more intimate contact. The damper is opened again, allowing the temperature to rise, and when the blue flames disappear the process is complete. The iron is in a doughy or pasty mass, it is made into balls and handled as previously described in the refining process.

There is a certain amount of loss due to oxidation of

the iron, but not as much as in the refining process, and as it is difficult to regulate the percentage carbon in the production without practically eliminating it altogether, the puddling process cannot be employed for the manufacture of steel, unless wrought-iron be first made and then afterwards treated. The disadvantage of the refining and puddling processes in the manufacture of steel is the necessity for the examination of the slag and the decarburised metal.

These disadvantages may be avoided by the use of the Bessemer process.

Bessemer Process of Steel Manufacture.

The principle of the process is the oxidation of the carbon in the iron, by blowing a stream of air through molten pig-iron. It is put into practice as follows:—

The fluid pig-iron is taken in a large ladle lined with fire-proof material, as it leaves the blast furnace, and poured into a pear-shaped holder known as a Bessemer converter. If the iron contains silicon, so much the better, as Bessemer found that the addition of iron containing silicon to the molten pig, which was free from silicon, caused the melting point to sink. This is most important for a process which depends upon the blowing of air into molten metal for completion.

The converter is shown in fig. 3. It consists of a vessel built of mild steel or wrought-iron plates riveted together and is lined with fire-proof material. It is supported on trunnions, one of which is hollow, and connected with the blast main, through which the air from the blower passes to the blast box at the bottom of the converter. The air passes into the converter through a series of holes in the bottom of the converter lining. The converter is turned on its trunnions, by

means of hydraulic power, till its axis is horizontal; when in this position and the air blowing, it is charged with molten iron, which is poured through the mouth. The fluid iron is put into a state of violent ebullition by the air blast (the axis of the converter being now vertical), the temperature rises, and the oxygen combines with the carbon, sulphur, phosphorus, and silicon. The gases escape as a light flame from the mouth of the converter, and the constituents may be

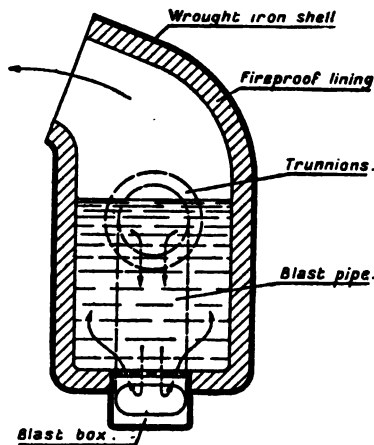


FIG. 3.—Bessemer Converter.

detected by means of the spectroscope. The carbon line is the last to disappear, at which time the process is complete. The converter is rotated on its trunnions, to allow the metal to be run into casting ladles. The casting ladle is a large vessel, lined with fire-brick, in the bottom of which is a hole, through which the steel is teemed into cast-iron ingot moulds of various shapes. The metal is teemed through a hole in the bottom of the ladle, to prevent the running of slag into the moulds, as the presence of such would affect, injuriously, the

quality of the steel. The ingots are taken to the mill for re-heating and rolling into the required plates or bars.

In spite of the ingenuity of the Bessemer process, which, on account of the short time of the blow (fifteen to twenty minutes) leads to the least loss from oxidation, there is a great disadvantage. The spectroscope shows that when the other impurities are removed the carbon shows no longer in the flame. Now, steel requires a greater percentage of carbon than wrought-iron, while at the end of the blow the metal is deficient in this respect. This is remedied by adding to the molten mass a quantity of ferro manganese or "spiegeleisen," sufficient to give the required percentage of manganese and carbon. Iron containing phosphorus to any great extent cannot be used in the Bessemer process unless it be first removed by another operation. This led to the invention of the Thomas and Gilchrist, or basic, process, in which pig-iron containing phosphorus may be used.

The Thomas Process.

This is carried out in a Bessemer converter, which is lined with a fire-resisting material having a great affinity for phosphorus, and in this way the use of pig-iron containing phosphorus is made possible. The process goes on in exactly the same way as in the Bessemer process, till the carbon is completely removed. The converter is not turned down at this stage, however, but the blow is continued for three or four minutes longer, being known as the "after blow." During this period practically the whole of the phosphorus is removed, combining with the lining of the converter and forming a slag. The metal is then cast into ingot moulds as before.

The Siemens-Martin Process.

A higher order of steel production is that known as the Siemens-Martin process, by which steel of the same name is made. It is carried out in an ingenious open-hearth furnace, in whose construction the brothers Siemens had the greatest share; and is called the Siemens-Martin regenerative hearth or furnace. It resembles, on the outside, the puddling furnace, but is capable of producing a much higher temperature, which is necessary to maintain fluid the iron, which, on account of the absence of carbon, has a much higher melting point. The process is carried out as follows: The hearth is charged, by means of hydraulic or electric cranes, with pig-iron and cheap scrap iron, the larger scrap being preferable to smaller. The charge is arranged so that the amount of carbon in the pig shall be just sufficient for the steel produced. Intense heat $1,600^{\circ}$ to $2,000^{\circ}$ C. ($2,912^{\circ}$ to $3,632^{\circ}$ F.) is maintained by means of a gas fire, which is produced in a generator, resembling (in principle) that which is used for the production of suction gas. The hearth is built with two chambers, one on either side, known as regenerators, which are filled with checker fire-bricks, through which the air and gas pass, on their way to the furnace, and through which the products of combustion pass, on their way to the chimney at the other end. One of these regenerators on each side is called the gas, and the other the air, regenerator, and they are separated by stout walls to prevent any mixing of the air and gas before they reach the hearth. The furnace and regenerators being heated up, gas and air are admitted through their respective generators on one side of the furnace, in which they take up heat, and meeting in

the hearth of the furnace, combustion takes place. The products of combustion circulate through both regenerators at the other side and give up the greater part of their heat to the brickwork on their passage to the chimney. At regular intervals the direction of the gas and air is reversed by valves so that the regenerators are alternatively heated up by the products of combustion, and cooled by the incoming air and gas. These operations will be readily followed on looking at fig. 4, which shows the directions of the flow of gases

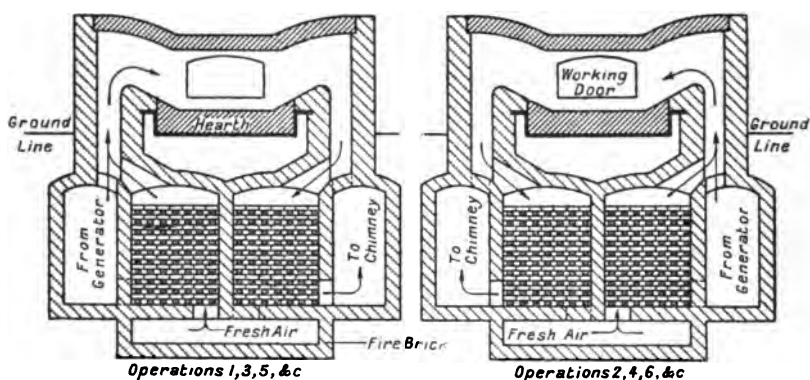


FIG. 4.—Siemens-Martin Regenerative Furnace.

for alternate periods. The impurities are removed as in the Bessemer process, the phosphorus forming a slag with the lining of the hearth and added dolomite, while the silicon is oxidised. The process is longer than the Bessemer process, occupying from three to five hours, but the loss by oxidation is less, as the metal is not violently agitated by air, and the steel produced is better.

The steel, made by the manufacturing processes already described, is known as mild steel, and is not suitable for the use of tools.

Cementation Process.

Steel for the use of tools is manufactured from wrought-iron by the cementation process, the original method of steel manufacture, and is produced as crucible steel or shear steel.

The wrought-iron bars are cut into lengths, packed in large boxes along with wood or animal charcoal, layer upon layer. The boxes are sealed with fire-clay to prevent oxidation of the metal by air, and the whole put into a fire and heated for a period of from seven to eleven days. The duration of heating and the temperature maintained depends upon the quality of the steel to be produced. When the heating is completed, the fire is banked up and the furnace allowed to cool down for a period of about fourteen days. When the steel (blister steel) is taken from the furnace, the carbon is not equally distributed throughout the whole mass. The outside layers, owing to their more intimate contact with the charcoal, have a larger percentage than the inner layers. To render the distribution of the carbon more uniform, three methods are employed :—

1. The steel is again packed in boxes and heated, without charcoal, during which time the carbon becomes more or less uniformly distributed. This process has the disadvantage of being too detailed and does not give good steel.

2. The bars of steel are bundled, heated, and well hammered together and rolled, the product being known as shear steel. It is probable that there is always some slag contained which is due to the oxidation which goes on during heating.

3. The best process is carried out in crucibles. The

bars are melted, and when fluid, the carbon is evenly distributed throughout. Oxidation takes place, but only at the surface, where it can be treated in such a way as to not affect the metal. The product is known as crucible steel, and is of first-class quality; it is ductile, dense, and hard, but also expensive.

In addition to the steels already mentioned, there is cast-steel, prepared by melting pig-iron and wrought-iron scrap together, the proportions depending upon the steel required. This is cast into moulds in the same way as cast-iron, care being taken that local strains shall not be produced in contraction and in the composition of the mould.

Electric Furnace.—Another means of producing the heat necessary for the manufacture of iron, and one that is increasing in application, is the use of the electric furnace. In this way steel of the highest quality, equal to the best crucible steel, can be made in England, where the cost of electric energy must be always somewhat high, at a price less than it costs to make the best crucible steel.

When steel of exceptional purity is required for special purposes, the electric furnace may, under very favourable conditions, be able to hold its own even against the open-hearth furnace. As regards the manufacture of structural steel (mild steel), the electric furnace cannot compete with a modern large open-hearth furnace; but this will not be the case when the electrical engineer can design a furnace of thirty or forty tons capacity to work satisfactorily.

The properties of iron and steel in relation to the various percentages of carbon are given in the opposite table.

Special Steels.—Outside this large classification there

TABLE OF PROPERTIES OF IRON IN RELATION TO THE
CONTAINED CARBON.

Pig iron, specific gravity 7·6, containing from 2·6 to 6 per cent. carbon. Melts easily at 1,200° C. (2,192° F.); not malleable.		Malleable iron, specific gravity 7·8, containing less than 2·5 per cent. carbon. Melts with difficulty at from 1,500° to 1,600° C. (2,732° to 2,912° F.).	
Steel with from 0·6 to 2 per cent. carbon is hard, dense, and has a silky fracture.			
<i>Foundry Pig.</i> Grey pig, containing silicon; the carbon exists as graphite partly free. Fracture, grey and crystalline. White pig, containing manganese; all carbon chemically contained. Fracture, white and silky. Harder and more brittle than grey.	<i>Refinery Pig.</i> For the Martin process, grey and white. For the acid process, less than 0·1 per cent. phosphorus; for basic process, less than 0·8 per cent. phosphorus. For the Bessemer process, grey, with less than 1 per cent. phosphorus. For the Thomas process, white, with more than 1·5 per cent. phosphorus.	Steel not made in the fluid state. Refinery, puddle, and cementation steel.	Steel made in the fluid state. Bessemer, Siemens' Martin, and crucible steel.
<i>Special Productions.</i> Ferro-manganese, containing up to 80 per cent. manganese. Ferro-silicon, containing up to 30 per cent. silicon.		Wrought-iron, containing from 0·4 to 0·6 per cent. carbon. It cannot be tempered, has a close-grained to crystalline and streaky fracture. Ductile.	
		Iron not made in the fluid state. Refinery and puddled iron.	Iron obtained in the fluid state. Bessemer, and Martin iron.
		Malleable castings: the amount of carbon is reduced by another operation after casting.	

If cast in moulds it is known as cast steel.

44 WORKSHOP MACHINES AND PROCESSES

are a number of special iron productions, of which the most important, for the engineer, are the special steels. The methods of manufacture are the secrets of the various firms engaged. A few of the more important, with their properties, are given below.

High-speed steel has the property of remaining hard when at a dull red heat. It is used for tooling hard metals and for working at a high rate of speed.

Self-hardening steel hardens in air without the necessity of cooling in water. It is used for machine tools.

Chromium steel, largely used for the manufacture of steel tires and springs in railway work.

Tungsten steel has, in addition to glass hardness, advantageous magnetic properties, and is used for electrical machinery.

Vanadium steel is not liable to become brittle when subjected to blows and shocks.

Nickel and silver steels are ductile and not easily affected by corroding influences.

The ultimate strengths and prices are given in a table later.

Choice of Material.—The descriptions already given of the metals and their properties will, to a certain extent, explain why a certain metal is used for one machine part while another is used for some other part. The choice of material does not altogether depend upon strength, and the engineer with a theoretical training will, by reflecting upon this matter, avoid many mistakes. The matter must be viewed from many points of view—how strength, possibility of working, resistance to wear and rust, affect not only the design but the cost. The absolute price of any metal used in the design is not of last importance; it will

depend upon the fluctuations of the market. But the average price of the finished design must be kept low. The current prices of the metals to be used, and any changes anticipated before the completion of the work must be carefully weighed before the final choice is made. Further, the cost of working necessary, as some metals are worked more cheaply than others. In regard to this matter, particular attention is directed to the table of prices of materials, in large quantities, given on page 53.

In addition to iron and steel there are several metals and alloys which find a place in machine construction, and a short detailed account is given below.

Copper, Specific Gravity 8·8 to 9.

Copper differs from iron in three important ways—it is more easily melted $1,050^{\circ}$ to $1,100^{\circ}$ C. ($1,922^{\circ}$ to $2,912^{\circ}$ F.); it is only with difficulty oxidised at ordinary temperatures; and in the chemically pure state it is very tough. In consequence of this, it can not only be easily forged when cold, but may be given more or less intricate shapes by pressing in moulds. Its strength is not as great as that of iron, but it may be increased by working (hammering and rolling) and reduced at pleasure by re-heating. By working in this way the tensile strength of copper has been raised to 58,000 lbs. per square inch, which is nearly as strong as wrought-iron wire. The great importance of copper to the electrical engineer on account of its electrical properties is well known; it is used by him chiefly in the form of wire. For mechanical engineering, however, it is almost universally used in the form of tubes, for which purpose it is admirably adapted on account of its readily yielding to changes of shape, even when

cold, and for its heat-conducting properties. If tubes are required to follow a tortuous path, involving short bends, as in the case of oil pipes, and steam pipes for small engines, copper is invariably used. It is easily bent in place, and the joints can be made with solder (if the pressure be not too high), or by brazing. The strength and electrical properties of copper depend, to a great extent, upon the chemical purity, the above desired qualities being present only in pure metal. In consequence of this, the refining necessary adds greatly to the cost, and copper is now produced by electrolysis, "electrolytic copper." Copper for use in alloys need not be as pure as the "refined copper" above; the latter is put on the market in the form of small ingots and bars, and when quite pure has a splendid silky fracture. It is seldom seen in the workshop, except in the form of wire, plates, or tubes.

Copper Alloys.

Copper and Zinc.—Brass or yellow metal, specific gravity about 8.6.

If copper and zinc be melted together in different proportions, the colour as well as the strength properties will change with the mixture. The changes are not strictly proportional to the percentages of the constituents, although they approach more nearly to those of copper as the amount of copper increases, but vary in an unsteady and undefined manner. They are not yet to be explained chemically, the whole of our knowledge of the subject being due to experience.

The strength, hardness, and ductility of the alloy, generally speaking, change with the amount of copper. As the zinc increases in the alloy, the ductility

decreases, while the strength and hardness increase, and this goes on till there is 50 per cent. zinc. If the percentage zinc be increased beyond the amount indicated the strength and ductility decrease rapidly. Thus the properties of a brass cannot be judged by its colour.

The brass used for engineering purposes usually contains 65 per cent. copper and 35 per cent. zinc. It is malleable when cold, in which state it can be rolled, but is brittle when hot. The tensile strength approaches that of copper, and it possesses a desirable property, which also belongs to copper, namely, the increase of strength and ductility with mechanical treatment. Brass wire has a tensile strength of from 50,000 to 60,000 lbs. per square inch.

Brass is much used in the form of castings; it melts at 300° C. and is thin fluid; it is difficult to oxidise, and gives good dense castings.

Copper and Tin.—Bronze, specific gravity 8.

Bronze is dearer than brass, because tin is more expensive than zinc. It is harder and more brittle than brass, and the colour, which changes with the percentage tin, does no more than indicate roughly the composition. The changes in the strength properties, compared with varying percentages of the constituents, are so great that the alloy has, deservedly, several names.

That used in engineering work known as gun-metal is only of interest. It is fusible, makes excellent castings, is harder and less malleable than copper. The proportions of tin and copper vary in different metals: thus soft gun-metal contains 8 per cent. tin to 92 per cent. copper; hard gun-metal contains 18 per cent. tin to 82 per cent. copper; while bell

metal contains 23 per cent. tin to 77 per cent. copper. A little zinc is often added to facilitate casting.

Ordinary bronze is not uniform in texture; whitish spots of alloy, rich in tin, are distributed through the mass. It has been found that when it is rapidly cooled after casting the composition is more uniform, the density greater, and the strength and toughness are increased. The process is carried out in the same way as that used for the production of chilled iron castings. Bronze is much used for bearings and small fittings.

Copper, Tin and Phosphorus.—Phosphor bronze, specific gravity 8·8.

Under this name an alloy has been introduced containing 90 per cent. copper, 9 per cent. tin, and 1 per cent. phosphorus, and is of great service in machine construction. It appears to owe its properties to the great care exercised in its manufacture and the accurate proportions of the constituents. Its qualities can be varied at will, so that it may be either very strong and hard, or, with less strength, ductile and very tough, and it resists the attacks of acids. Unlike ordinary bronze, it can be remelted without deterioration of quality.

Its tensile strength varies from 22 tons per square inch in the softer qualities, to 33 tons per square inch in the hardest. The elastic limit of the former is about 5 tons per square inch, and the latter 25 tons per square inch. The former elongates 30 per cent. or more before fracture, and the latter 3 to 4 per cent.

Unannealed wire (16 B. W. G.) broke with from 102 tons per square inch to 151 tons per square inch, and the same wire after annealing carried from 48

to 74 tons per square inch. When subjected to wear it lasts much longer than gun metal and is particularly suitable for large crank and footstep bearings.

Copper, Zinc and Iron.—Delta metal, specific gravity 8·6.

This is a brass containing a proportion of iron. Its strength, 21 tons per square inch tensile, approaches that of iron, and after being worked it surpasses it, 33 to 35 tons per square inch tensile. It can be forged hot or cold, and may be cast, giving good sound castings. It is difficult to oxidise, and resists the action of acids, for which reasons it is chiefly employed in shipbuilding, pump and turbine work.

Copper and Aluminium.—Aluminium bronze, specific gravity 7·7.

This is a bronze with a small proportion of aluminium, and can be made of great strength and toughness. The most suitable alloy contains 92 per cent. copper and 8 per cent. aluminium. It is very thin fluid when molten, and can therefore be applied to intricate castings, and is much used in the manufacture of small engines and fittings. As the price varies from 8 to 10 times that of cast iron, it is seldom used in large castings.

Aluminium bronze is also useful in iron and steel casting, as a small proportion added to the fluid iron or steel reduces the amount of gas given off, and makes the castings more dense.

Alloys of Tin.

The only alloy of tin, except those containing copper, which is of use in machine construction is that known as white metal. It is an alloy of tin and antimony, of specific gravity 7·1, and containing 80 to 90 per cent.

tin, 7 to 13 per cent antimony, and 3 to 9 per cent. copper.

The object of these alloys is to obtain a metal for bearings which is cheaper and softer than ordinary gun metal, and which works with less friction. The friction depends upon the way in which the bearing wears. If it be soft and of uniform texture, and wears with a smooth polished surface, the friction may be expected to be small. Some of these alloys are fusible at a low temperature and are cast in position round a smooth mandrel. They are too soft to be used for large bearings, and are cast in the form of a layer in a gun metal bearing. The objection to the softer alloys is that they crush and clog the oil channels.

Another useful alloy of tin is solder, but this will be referred to in a later part.

Cost of Raw Material.—The whole of the materials which are used to any extent in engineering work have been referred to. The question which remains to be dealt with is that which considers the relation of strength and weakness to cheapness and expensive-ness. A knowledge of the previous work will give the young engineer a first idea why a certain material is used for a certain object; but this is not sufficient.

A knowledge of the proportion of cost of raw material to the cost of working necessary to produce the finished article is necessary. Such knowledge is absolutely necessary to the present-day engineer, and gives him a feeling of confidence in his designs. The influence of later work and later material must be carefully estimated and set down, as the saving of some working cost may entail the use of more material; and conversely. The expert estimation of these proportions, by examining possible constructions, enables the

designer to choose, quickly and correctly, the amounts of working cost, and cost of material which are best for true economy. Continual observation of these amounts for single finished articles, is the only means of acquiring the capability of making this estimation.

Estimation of Weight.—The estimation of cost depends, apart from the cost of material and working cost, upon the weight of the finished article. Again, it is often necessary to consider, in addition to the forces which act upon any machine part, the effect of the weight itself, so that the estimation of weight becomes an important item for the designer's consideration. Now weight may be measured directly by means of scales or weighing machines; it may be calculated from the known weight of the material; or it may be estimated from previous experience. In the case of the action of forces, together with the action of weight, it often happens that there are no data available for calculating weight, unless a large amount of time is taken in calculating and re-calculating. To avoid, as much as possible, any waste of time in this direction, the young engineer should train himself to estimate weights. To this end he must learn to measure correctly, using at first the straight-edge, calipers, micrometer-calipers etc., until the time arrives when he has measured a certain number of standard articles so often, that he can pick out the size by glancing at it only. As the number of standard sizes which become impressed upon his memory increases, the less often will he require the rule for purposes of estimation. Having become proficient in the estimation of measurements, it will be but a short step to the estimation of weight. The weights of simple geometrical bodies are to be estimated, and then checked by weighing and, being

52 WORKSHOP MACHINES AND PROCESSES

memorised, they form the basis for the estimation of the weights of plates, bars, etc.

To calculate the weight of a body we multiply together its volume in cubic inches (or cubic feet), its specific gravity, and the weight of one cubic inch (or cubic foot), of water in pounds. The result will be the weight of the body in pounds. A circular wrought iron bar, 3 inches diameter and 10 inches long, weighs :

$$\frac{\pi 3^2}{4} \times 10 \times 7.8 \times 0.0362 = 19.7 \text{ lbs.}$$

In the above calculation the product of the specific gravity and the weight of a cubic inch of water gives the weight of a cubic inch of the metal. It will be seen, therefore, that it is simpler to calculate the weight by multiplying together the volume and the weight per unit volume. For the different metals the weights per cubic inch are, in pounds :—cast iron, 0.26 ; wrought iron, 0.277 ; steel, 0.283 ; brass, 0.3 ; bronze, 0.3 ; copper, 0.318 ; lead, 0.411 ; tin, 0.27 ; zinc, 0.248.

A cast iron bar, 8 inches by 6 inches by 20 inches long, weighs :—

$$8 \times 6 \times 20 \times 0.26 = 249.6 \text{ lbs.}$$

A mild steel plate 6 feet by 3 feet by $\frac{1}{2}$ inch thick weighs :—

$$72 \times 36 \times \frac{1}{2} \times 0.283 = 366.77 \text{ lbs.}$$

The high degree of development to which the moulder has attained in the estimation of weight is worthy of admiration. He can, by walking through the foundry and inspecting the moulds which are to be used during the day, determine the amount of charge necessary for the furnace to a great degree of

accuracy. This is an important point in a large foundry, as an excess of only 10 per cent. in the charge means that a large quantity of fuel will be uselessly burnt.

Having estimated or calculated the weight of a single article, the following table may be used for the estimated cost of material. It gives the average prices of the various metals in bulk, but they are by no means fixed.

TABLE OF AVERAGE PRICES PER TON OF VARIOUS METALS.

	£	s.	d.	£	s.	d.
Pig iron.	2	13	0 to	2	17	0
Cast iron (castings)	7	10	0 „	18	0	0
Wrought iron (bars)	6	15	0 „	8	10	0
Swedish charcoal iron	18	0	0			
Bessemer steel	6	10	0			
Siemens-Martin steel	6	7	6			
Shear steel	2	4	0 to	2	10	0 per cwt.
Crucible steel	0	14	0 per cwt.			
High speed steel	0	1	9 per lb.			
Self-hardening steel	0	1	6 to	0	1	8 per lb.
Copper	63	0	0			
Brass	0	0	7 per lb.			
Gun metal	0	0	10 „			
Phosphor bronze	0	0	10 „			
Delta metal	0	0	11 „			
White metal	0	1	0 „			

The following table gives the ultimate tensile strength, the elastic limit and the elongation for the various metals. It must be remembered that average values only can be given, as the strength of a metal produced by one maker may be quite different from that of the metal produced by another maker. At the same time, all the metal from one factory will approximately have the same strength. As an example, it will be noticed in the table that the strength of cast steel gradually approaches that of ingot steel, so that while a certain figure may represent the strength of ingot steel from

54 WORKSHOP MACHINES AND PROCESSES

one district, it may also represent the strength of cast steel from another district.

The tensile strength (ultimate) and elastic limit are given in tons per square inch, while the extension is expressed as a percentage, and is obtained by dividing the elongation by the original length, and multiplying by 100.

TABLE OF STRENGTHS, ELASTIC LIMITS AND ELONGATIONS.

Material.	Tensile strength. Tons per □".	Elastic limit. Tons per □".	Elongation. Per cent.
Cast iron . . .	7·0 to 15·0	7·0 to 15·0	Changeable.
Wrought iron . . .	19 to 25	15 to 16	30
Cast steel . . .	22 to 27	16 to 17	24
Crucible steel . . .	53	27	18
Steel plates . . .	28·5	18	30
Steel bars . . .	28·5	18	30
Steel wire . . .	60	50	8
Nickel steel . . .	42	28	23
Ingot steel . . .	27 to 54	14 to 27	18
Copper . . .	14	4	37
Brass . . .	10 to 12	6	13 to 22
Delta metal . . .	24	9	10
Phosphor bronze . . .	16	—	—

Some Remarks on the Choice of Materials.

The remarks already addressed on the various facts which have to be considered when choosing material, puts us in a position to review the connection between them.

The choice of a metal for any machine part depends principally upon the object of the finished article, strength, possibility of machining, price, and weight. The material selected will be the one which possesses the greatest number of the above properties in the most favourable manner.

For large cranks subjected to heavy and fluctuating

loads we would only use the best steel, as this material withstands the forces and wears well. On the other hand, a large steam or gas-engine cylinder would not be made of any other metal than cast iron, as, on account of the intricate shape, the manufacture is only to be performed by casting. Copper alloys may be cast, but the price is against them, being from eight to ten times the price of cast iron ; further, cast steel is not applicable to intricate castings on account of its thick fluidity. Cast iron is so indispensable to this kind of work, that the large gas-engine industry would not be in the flourishing condition it is in to-day if it were not possible to cast large cylinders which can be guaranteed to stand the explosive pressures used.

When the demands on the material are not so stringent as those above, the designer may consider the price to be the most important property. A good example of change of design in the same article due to price is afforded by bearings. For small bearings gun metal is almost exclusively used as it is easily cast and machined, and works well in contact with iron and steel journals. An alternative to gun metal is white metal, which also makes a good bearing surface, but owing to its lack of strength, must be supported by a frame in the form of a cast iron pedestal or a gun metal step. The gun metal step is invariably used, and the white metal cast in position on a mandrel. When the bearing exceeds 4 inches diameter the cost of a bearing in gun metal exceeds that of a bearing lined with white metal, as the saving in the cost of gun metal exceeds the extra work and cost on the white metal lining. For this reason large bearings are always lined with white metal.

The question of weight and cost is illustrated by a

beam or bridge. The manufacture of rolled sections was not developed till after the middle of the 19th century. Up to that time the price was very high, and cast iron was always used in bridge construction, while at the present time cast iron is seldom used. We see from the table of strengths that wrought iron is, roughly, three times as strong as cast iron, so that for the same loads a cast iron bridge must have three times the area of a wrought iron bridge, and consequently three times the weight. Now the cost of cast iron is, roughly, £9 10s. per ton, while wrought (rolled) is £7 10s. per ton, so that the costs of material for the same bridge are in the ratio of 4 to 1, wrought iron being the least. Of course the wrought iron bridge must be built up and riveted together, while the shape is given to the cast iron in the mould; but as a riveted joint is an inexpensive form of fastening, the finished bridge of wrought iron is cheaper than cast iron. Another and important point in favour of wrought iron is that of transport, as large castings often necessitate special rolling stock.

On the other hand, there are cases in which weight is a desirable thing, an example being the frame of an engine. The engine must be firmly fastened to a foundation to prevent its motion about the engine house, and the heavier the frame the less weight of foundation necessary. Again, the rapidly fluctuating forces would tend to loosen the joints in a frame which was built up of rolled sections, and this danger is eliminated by having it cast in a single piece. There are times, however, when lightness is the important factor, as in locomotive building, and the frames are built up of rolled sections.

These remarks indicate the steps taken by a designer

in the choice of his material. They are not to be taken as complete, but merely as a guide to the intelligent young man's faculty of observation. He must always be on the look-out for something new to him, reflecting upon the why and wherefore, and, if necessary, not be afraid to ask questions regarding any doubtful point. In this way he will, during his stay in the workshops, go a long way towards the acquirement of the "engineering instinct" mentioned previously.

B.—Manufactured Iron.

There is a branch of the iron industry which stands apart from the manufacture of pig iron. It is known as rolling, and is responsible for the production of all sectional iron and steel work, plates, bars, rails, wire and tubes.

It would be impossible for any engineering works, no matter how large, to run economically a rolling mill plant; as the machinery would be idle for the greater part of the time, taking up valuable space and, so to speak, eating up rent. It is for this reason that the manufacture is carried out in rolling mills, devoted solely to this work. As the metal has to be worked when hot, the process is best carried on in conjunction with smelting; and rolling mills are usually found adjacent to the blast and puddling furnaces. The machinery used is very heavy, as large forces are required, and the work is produced in sets, that is, a number of bars are rolled at one time and of one section, the rolls are changed, and a second set done.

Standard Sections.—As the rolling mills turn out work for all parts of the world, it is necessary that standardisation be adopted; not only for the engineer, but also for the iron manufacturer. Thus the costliness

of the plant necessary for manufacture (each section requires particular rolls, gauges, etc.) is reduced to a minimum, and the engineer has the best conditions for economical working.

The standardisation, as far as England is concerned is in the hands of the Engineering Standards Committee, which is composed of the leading British engineers. They issue books and sheets relating to various manufactured articles (iron and steel sections, bolts, nuts, rivets, etc.).

The principal sections as rolled in iron and steel are as follows:—

Bars.		round.		channel.
		square.		H (rolled joist).
		flat.		Z.
		hexagon.		bulb T.
		T.		bulb flat.
		angle.		

The section **I** rolled in iron is called an “H iron,” while in steel it is called a “steel H section,” and not an “H steel.” The vertical part of the section is called the “web,” the horizontal part the flange, while in the case of bulb T’s we have the head, web and sole.

We may now look briefly at the various methods of producing standard sections.

Rolling.—All processes employed for the manufacture of steel and iron sections, plates, and wire, depend upon the malleability of the metal. Thus metal such as wrought iron, steel, copper, and the malleable alloys such as phosphor bronze, delta metal, and brass, can only be used. The principal method of manufacture is rolling, and this takes its name from the rollers

which are used. It is unnecessary to go into this process beyond remarking that great forces and high temperatures are employed. The refinements of the machines and the manufacture of the rolls must be left for the theoretical study.

Sections, plates, and wire are manufactured by rolling, and the quality of the material is enhanced by the kneading and pressing together of the particles.

Drawing.—This consists in drawing the hot metal through a conical hole in a steel die or plate, the length increasing as the section decreases. The whole process is carried out by drawing the metal through a series of dies of different sizes but of the same shape, (not necessarily circular). The smallest and last die of the set will have the same size as the finished wire (drawing is not resorted to for any solid section but wire). Tubes of superior quality are also made from thin bar iron by drawing in this way. A mandrel having its diameter equal to that of the hole in the finished pipe is placed inside, and the edges are welded together by the pressure in passing through the die. The strength of the metal is increased by drawing, and brass wire can be obtained of great strength.

Pressing.—The body of the press is filled with hot metal, the only outlet being through a small hole in a steel die. Hydraulic pressure is put upon the press and the metal is forced out in much the same way as meat from a sausage machine. It becomes bars or tubes in accordance with the kind of die used.

This process is only applicable to metal at a temperature considerably below the melting point of the iron press, as otherwise the heat would melt the iron. The pressures used are as high as four tons per square inch, and in the aggregate, on large areas, may

rise to thousands of tons. The pressing together of the metal in this process increases the strength more than rolling or drawing.

Special Productions.—The hydraulic press may be used in another way, stamping out the shape by means of steel punch and die. The process is completed in one pressure, and the time of contact between the punch and the hot metal is therefore short, so that this process may be employed for iron and steel articles. Boiler ends are made in this way; and of small articles rivets are most important.

There are further special articles of large size which, although not standardised, are really a special manufacture. This is due to the fact that many workshops do not possess the large furnaces and presses necessary for the work. For example, there are large cross heads, large crank shafts for marine engines, etc., and these are obtained directly from the mills.

Finished Fittings.—In addition to the production of pig iron and rolled sections, there is a branch of manufacture which has been very largely developed. There are many large works to-day which are devoted exclusively to the manufacture of those fittings which, though often small, are indispensable to engine building and machine construction. Examples of such fittings are to be seen in all erecting shops: for example, bolts and nuts, valves, lubricators, etc.

The young engineer whose lot is cast in a works in which these fittings are manufactured, is not less fortunate than one who works in a large engine manufactory. In fact, he may have the advantage, because he learns the most intricate form of manufacture, in addition to production in bulk.

The manufacture of fittings in bulk increases from

day to day, not only in extent, but also in the number of different types produced. It has reached such an extent in the motor-car industry that some French and American automobile works confine themselves solely to the erection of machines, buying the parts, even the engines, ready finished from the manufacturer.

That such a business can be run economically is due to the fact that the manufacturers have the same men working on the same part year in and year out, and in this way produce the fittings at a much smaller cost than the users themselves could.

Under these conditions it would be impossible to deal fully with this subject, but we may refer to one or two things which, on account of their standard character, call for some mention.

Screws, Bolts and Nuts.—All screws used in England, except those for bicycles and very small screws, have the Whitworth thread, as proposed by the late Sir Joseph Whitworth at the time the standard was adopted. For all diameters of screw the shape of the thread is the same, but the size differs. The diameter of a screw or bolt is taken outside, or on the top of, the thread; and starting at $\frac{1}{4}$ inch, it increases $\frac{1}{16}$ inch at a time to $\frac{1}{2}$ inch diameter. Between $\frac{1}{2}$ inch and 1 inch diameter it increases $\frac{1}{8}$ inch at a time, and above 1 inch it increases $\frac{1}{4}$ inch at a time. The number of threads is quoted as so many per inch, and is greatest for the smallest diameter. The nuts are standard and are square or hexagon, while the bolt heads are usually square, hexagon, or countersunk. In addition to bolts and nuts, there are studs, stud iron, set bolts or set screws, grub screws and screws with countersunk heads.

Pipes.—Tubes or pipes made of iron from flat bars

as previously referred to, are known as gas piping. The size is taken in the bore or hole of the pipe, so that a $\frac{1}{2}$ inch pipe measures $\frac{1}{2}$ inch in the hole, the outside diameter not being taken. The threads are Whitworth standard but of much finer pitch; for example, a 2 inch pipe has 11 threads per inch while a 2 inch bolt only has $4\frac{1}{2}$ threads per inch.

The pipes are associated with fittings of different shapes by means of which they may be made to follow more or less tortuous paths, the jointing being done with red or white lead. They are used for all low pressure work for water, oil, gas, etc., and make a cheap and quickly erected form of light hand rail. A pipe of the same size as the gas pipe but stronger, is much used for small steam pipes. A still stronger wrought iron pipe is used for hydraulic pressure. For large diameter water and steam pipes, cast iron and steel are used.

The various fittings for pipes are : flanges, loose rings, blind flanges, elbows, bends, T-pieces, cross-pieces, couplings, nipples, lock nuts, blank couplings, spigots, and sockets. For boiler work there are : Galloway, Field, and corrugated tubes ; fire and water tubes, and expansion joints.

The subject of piping leads us to a large branch of the manufacture of finished parts, namely, valves.

They are made in the same sizes as pipes, and are constructed of cast iron, cast steel and gun metal.

There are straight-way, three-way, quick-closing, check safety valves, sluice valves and cocks, and in addition, water gauges and small boiler mountings.

Lubricators.—Lubricators are manufactured in large quantities, and, on account of the magnitude of the trade, they are more or less standardised. They are

produced cheaply and of great reliability, a most important point, as efficient lubrication is necessary for the life of machinery. The chief lubricants are: Stauffer, needle, wick, sight feed, drop, and ring.

In addition to these, there are the oil pumps and fittings necessary for the forced lubrication system, in many engines of to-day, which closely resembles the system of blood circulation of the human body. In conclusion, we may briefly mention lubricants, of which there are three kinds:—

1. The thick or semi-solid lubricant, which is partly vegetable or animal, and partly mineral. It is used for less important bearings and links.

2. The thin fluid mineral oil, which can be easily dropped at ordinary temperatures. It is used in needle and wick lubricators for all bearings and links which are not enclosed.

3. The thick fluid mineral oil which becomes thin at high temperatures. It is used in engine cylinders, from which application it gets the name “cylinder oil.”

CHAPTER IV

FOUNDRY AND PATTERN SHOP

FOUNDING and pattern making cannot be considered separately on account of the dependence of one upon the other. For certain and efficient working operations should be carried on in two distinct but neighbouring workshops, and the work in each should be carried out together instead of independently.

Now the work of the pattern shop cannot be intelligently performed without a knowledge of moulds and moulding processes, and for this reason the stay in the foundry should precede that in the pattern shop. It often happens, however, that the young man is not allowed any time in the foundry; while if he is, is only allowed to work there at a time which suits the convenience of the manufacturer, without any regard to his training. It is often the practice in England to send the apprentice into the pattern shop first; but this is wrong, as there is no better way of learning the requirements of patterns, cores, boxes, etc., than by actual use and observation in the foundry. For the sake of those who cannot get foundry experience and for those who may go into the foundry in the future, a few detailed descriptions of the various processes are given. They will probably assist the former and act as a guide to the latter.

The production of a casting involves three principal processes: the making of the mould, melting, and casting; and they may be considered in this order.

Making the Mould.—Each material to which we give a desired form by casting must be, when molten, poured into a mould which has all the peculiarities of shape of the required casting, but in a hollow form. We may, so to speak, call the mould the negative of the casting. This is done by first making, from some suitable material, a pattern which has the shape required. The pattern is then surrounded by some moulding material which is capable of taking the shape and of supporting itself when the pattern is removed. After the pattern is removed, the possibility of which is ensured by the process adopted in making the mould, a hollow space remains which is the negative of the casting. The molten metal may then be poured through a hole made for the purpose, and when the whole is cool the casting may be taken out.

The simplest form of mould consists of a hole scooped out of the moulding material, but this is only suitable for simple shapes which have flat tops. The simple open mould would not be suitable for a ball casting, which would require a pattern.

Division of the Mould and Pattern.—In making the mould for a ball it will be seen that the work is not so easily and quickly done. The question arises, how can we take out the pattern without destroying the mould? We cannot do otherwise than arrange the mould in two parts which, when separated, allow the pattern to be taken out. To this end, two cast iron frames (moulding boxes) are taken which fit together. One is laid on the ground and filled with moulding material (sand), and in the sand the ball pattern is put, so that its diameter lies in the surface. In this way the lower half of the mould is prepared, and the pattern can be easily lifted out without disturbing

it, as the pattern tapers away from the surface. The surface of the sand is covered with a material to prevent the sand in the top box adhering to that in the lower, and then the top box is put on. Sand is put in till the top half of the mould is prepared as was the lower. If the top box be now lifted off, the pattern may be taken out, and we have two half moulds for a ball. The boxes are not ready for putting together as the mould is not yet complete, there being no hole through which to pour the molten metal. The requisite hole is made by the moulder and is known as the "git," or "gut"; in addition, he makes one or more small holes for the escape of the air contained in the mould before filling. These latter holes serve the additional purpose of showing, by the flow of metal through them, when the mould is completely filled. After the metal has cooled, the mould is broken open and the casting taken out with the adhering moulding sand and the metal "git." The sand is removed by wire brushes, and the git is cut off with a chisel or saw, and a ball casting is the result.

In the case of intricate castings it will be found that very often the pattern cannot be taken from the half mould without destroying it. When this is so the pattern is divided in such a way that the greater part can be taken from the half mould without destruction, leaving the "loose pièces" to be taken out afterwards.

The comparatively simple example of the ball shows us that it is not so easy to cast even simple bodies. The principal things necessary for general moulding are: the pattern, the moulding material, and the moulding box. Let us see what function each has to perform and how it does it.

The pattern must, generally, be made in two or

more parts. As the distance from a plane of separation becomes greater, the size across must get less, *i.e.*, the pattern must taper. This law of taper is universal, and parts of castings which when finished are to have parallel faces must have a slight amount of taper on the pattern. Further, any projection which would remove the sand in being taken from the mould, must be constructed as a loose piece. Where the pattern is divided, dowels must be provided to ensure that the parts always go together in the same way. The surface must be very smooth, preferably varnished, to facilitate the "draw," or taking-out. Finally, there are the questions of durability, strength, ease of manufacture and cheapness of the pattern.

Wood is the material which answers the latter claims most successfully, and it is almost exclusively used for patterns. It can be quickly shaped, in the lathe or on the joiner's bench, to the simple prismatic forms which are chosen by the designer. Further, the rounding of edges and corners, as well as the making of holes for lifting, is a very simple matter, and the whole pattern can be therefore easily made with joiners' tools. The only exception is the scale or rule which is specially made to allow for the contraction of the metal in the mould.

The draw of the pattern can be rendered easy or difficult by the design adopted by the engineer, and this illustrates the value of foundry experience to the designer. There are, however, other questions of importance to be considered. The art of founding has been brought to such a state of perfection to-day that absolutely all shapes may be cast. But the intricate and costly processes involved at times, and the degree of uncertainty in the result, are matters

for serious consideration. The design should always tend towards the simplest pattern procurable, as the additional cost owing to the bad casting of intricate shapes may be greater than the value of the casting itself.

The division of the pattern referred to previously is one of the principal examples to be learnt during the work in the pattern shop and foundry. The young man must compare the demands of the designer with the work of the pattern maker and, when several alternatives are open, determine why the one adopted was used in favour of the others. Much information on this point can be obtained from the foremen moulders and pattern makers.

Moulding Material : Sand.—After the making of the pattern, we proceed to the question of material for the mould. Whatever is used must have sufficient cohesion to hold together in the mould and support itself. It must also be fireproof to withstand the high temperature of the molten metal, and it must be sufficiently porous to allow gases to escape. This because iron when fluid is a great absorbent of gas, which it gives out again on cooling. This explains why the choice falls upon finely ground material, which at first sight would appear surprising, on account of its low degree of firmness.

Green Sand.—Fine green sand is the best moulding material for cast iron, this being the result of the experience of generations of iron founders. It consists of a mixture of silica (chemically pure sand) with small amounts of alumina, lime and iron oxide. At times it contains magnesia, alkalies and organic substances (horse dung, etc.). The silica makes the sand fire-resisting, while the cohesion arises from the

alumina combining with the water, partly chemically and partly mechanically. When the sand is dried, in the oven or by coming in contact with the hot fluid metal, the water is driven off, and it becomes porous, while at the same time it loses its plasticity. When in this porous condition it lets the gas escape freely. In addition to becoming dry the sand changes in chemical composition, so that before using again it must be mixed with fresh moist silica. In this direction it will be found that sand which is good in many respects is not used, because it loses its nature during one application. The life of a sand depends largely upon its fire-resisting properties, which may be relied upon to give an idea of its value. These properties depend upon the amount of free silica, and the test for them is a chemical one. When the ingredients have been determined and weighed out, they are mixed by hand or more quickly by mixers, a process which is increasing in application in large works.

Moulds made of green sand do not possess great strength, but as a whole may be strengthened by means of ribs in the moulding boxes and pegs in the moulds. These stiffening methods do not support edges and corners in any way, which are, therefore, liable to be broken off if the stream of fluid metal is in any way large. If this happens, the casting will have too much metal in the places from which the edges have been taken, and not enough in those to which the broken edges have floated. The consequence will be a bad casting or "waster." To obviate this difficulty all corners should be rounded and, if the mould be then weak, it may be mixed with larger proportions of alumina and organic substances. It becomes then a comparatively greasy form of sand

and is capable of withstanding great pressures, so that it may be used for very large castings. It is less porous than green sand, as the hasty heating by the fluid metal does not render it quickly porous ; the gas cannot escape and the mould is in danger of explosion. It follows then that large moulds made with this sand must be well dried before casting, and as the size will not allow them to be put in an oven, it must be done with portable lamps or heaters.

Loam.—Loam is a sand of yellowish red colour, of great cohesion when moist, and great porosity when dry. It is much used for the cheap production of large moulds, but must be well dried before casting. The mould is roughly fashioned with bricks and then a layer of loam is laid on and smoothed to the required shape. It is almost exclusively used for brass castings of all sizes.

There are many auxiliaries to the use of moulds, such as spikes and plates for the support of cores and internal parts of moulds, tubes of small size which, when embedded in the sand, form outlets for the escape of gas, etc. A knowledge of these, as well as the desirability of well ramming the sand to form a compact homogeneous mass, are best learnt by actual work in the foundry. It must not be forgotten that it is better to ask questions on doubtful points than to be silent and ignorant.

Moulding Boxes.—The functions of moulding boxes must be performed by simple means in a simple manner. They are made of cast iron, and usually consist of a frame in two parts which fit together. For the more difficult or intricate form of casting they may be in three or more parts. Where the parts join the edges have projections which have pegs or dowels

in one to fit into corresponding holes in the other. This ensures that the boxes shall always fit together in the same way. Small boxes have handles for convenient lifting, while large heavy boxes have projecting pegs to take chain slings which are attached to overhead cranes. When the frame is of large size a number of ribs or bars run from side to side, and of varying depths, depending upon the form of mould required. They support the central part of the sand, which would otherwise tend to break through owing to its great weight.

Cores.—Having considered the work involved in the production of solid castings, we must pass on to hollow bodies, which represent the greater number of castings required in engineering work. Let us take our previous example of the ball, but instead of it being solid we shall deal with the moulding of a hollow ball. How do we make the mould? We must take steps to prevent the whole of the space being filled with metal. To this end we place a sand “core,” inside; that is, we partly fill the hole with sand in such a way that the space remaining between the mould and core shall be the same as the required thickness of metal in the ball. The pattern can only give the outside shape of the casting, so that the core must be made separately and laid in. We regarded the mould as the negative of the casting, and in the same way we may regard the core as the positive of the hole to be left in the ball. It will therefore be produced in the same way as the casting is in the mould; but instead of sand we use wood for the negative, and instead of metal we use sand for the positive. The “core-box,” as it is called, resembles a cake mould which is made in two parts. For the hollow ball we must take two wood blocks and

scoop out a space in each of the size of the interior of the ball. Both blocks are made to fit correctly on each other by means of dowels and holes, so that they always fit in the same way with the large diameters together. A hole is bored from outside to inside with its axis lying in the plane of separation, and is intended to provide a hole in the casting through which the sand core may be taken out after casting. The ball may be made with an unbroken surface, but then a hole would have to be drilled to let out the sand. After being taken from the core box, the core is dried in the core oven, becoming dry and hard; it can then be put in place in the mould. A new difficulty arises in the supporting of the core. It must be held in the correct position to give the requisite thickness to all parts of the casting; and so firmly, that it cannot be displaced and floated away when the metal is poured in. This can be done by means of core supports consisting of small square plates, which are put, as many as necessary, in the space between the mould and core. They melt, and are absorbed in the iron when it is run in but remain solid long enough to keep the core in the right place. We may also get a certain amount of support from the projection left to form the hole for the removal of sand. If this be fitted into recesses in the mould prepared for it, it becomes to a certain extent self-supporting.

The casting taken from the mould prepared in the way just described is a hollow ball having a hole in one place. We see that it is impossible to get a hollow cast iron ball, as a hole must either be cored or drilled to let out the sand. This is a point that is liable to be overlooked by the novice, and must always be attended to. If the surface is to be unbroken by any

holes, the hole previously referred to must be closed either by a screwed plug or a plug driven in ; otherwise it is left open.

It often happens that holes are not objectionable, and when this is so it gives us a better means of supporting the core. The ball core can be made with two projections, instead of one, on opposite sides. It will then represent a sand ball on a sand shaft, which shaft may be used for supporting. If the shaft be laid in bearings prepared in the mould, we have the core entirely self-supporting.

Prints.—The recesses in the mould which, for the sake of illustration, we called bearings, have to be made in the right place. This is done by putting “ prints ” on the pattern, which prints consist of pegs of the shape and size necessary to form the required recesses.

Prints are coloured distinctly from the pattern, usually red, and anyone not familiar with moulding is prone to wonder of what use they are, and why they are not reproduced in the casting.

When plain cylindrical holes are required it is not usual to prepare core boxes, but only to put prints on the pattern, the simple core being made by the moulder and of the same size as the prints.

Fitting Strips.—Fitting strips are thin strips, about $\frac{1}{8}$ inch thick, placed on surfaces which have to be machined and which are not necessarily to be smooth all over. They are designed to reduce the amount of machining to a minimum without affecting the strength and rigidity. The base of a plummer block is a good example of the use of fitting strips. They are cast round the edges of the base, and if the base be large, several may run across from side to side. The time taken to machine the comparatively narrow strips will

be much less than that required to machine the whole surface, if it had no strips. The plummer block will sit quite rigidly on the bed or frame designed to take it, and, if the strips be made large enough, will have ample strength.

In the case of wearing surfaces fitting strips are not permissible, and an extra thickness of metal must be allowed for in the making of the pattern. Further, spaces are to be left to provide clearance for the cutting tools of planing and slotting machines.

Striking Boards.—The making of large moulds is often rendered easier by the use of striking boards. The affection of the engineer for circular shapes, *i.e.*, solids of revolution, does not depend upon appearance, but upon the extraordinary cheapness and convenience of their production and working. We have already seen that patterns of circular section can be quickly and easily made in the turning lathe, but a much cheaper casting can be made if the pattern can be dispensed with. The mould can be made without a pattern by taking a board having the section of the required mould (striking board) and rotating it about an axis. The axis is placed in the sand, preferably vertically, when by rotating the striking board the required mould is struck out.

This process can be used for the production of cores as well as moulds, in which case the striking board is stationary while the sand is made to revolve. The axis, which is horizontal for cores, has straw bound round it and is then covered with loam; this is rotated and the striking board held up to it till the core has the correct size and shape.

The making of moulds by striking boards is invariably done in loam, which is much more cohesive than sand.

As an example of the process, the following is a description of the making of a mould for a large screw propeller:—

It will be obvious that to make a wooden pattern for a casting which may have a diameter as large as 25 feet and weigh over 15 tons would be a very expensive proceeding. For small propellers, especially when several castings are required, and for small detachable blades, wooden patterns are made; but for the larger sizes the mould is struck out in loam. Suppose the propeller is to be 15 feet 6 inches diameter, and to have a pitch of 18 feet, the tangent of the angle of the screw, which is measured by the pitch divided by circumference, is calculated, from which the angle is found to be about $20\frac{1}{2}$ degrees. Let us suppose that there are to be four blades; then the pattern maker takes a piece of thin wood, from which he cuts a template in the form of a right-angled triangle, with the angle between base and hypotenuse equal to $20\frac{1}{2}$ degrees. If the length of the base be equal to one quarter of the circumference of the propeller, the hypotenuse, when the template is bent into a circular arc of 15 feet 6 inches diameter, gives the required screw for one quarter of a turn. A circular pit of from 18 feet to 20 feet diameter is dug in the foundry floor, in the centre of which a circular shaft about 4 inches diameter is placed truly vertical. On the shaft there fits a collar, to which is attached a striking board capable of revolving freely and at the same time rising or falling on the shaft. The collar and board are counterbalanced by means of a wire rope running over a pulley at the top, to the end of which a weight is attached. The template is curved as described above and firmly fixed in position, giving what is known as

the "race," which, when ready, resembles the hand-rail of a spiral staircase. If the striking board be rotated while at the same time its outer end is kept in contact with the race, it will be evident that a screw surface will be generated by the edge. A foundation of brick is built in the position of the four blades, the striking board being used to ensure that a space of about 3 inches shall remain to be filled with loam. Loam is laid on the brickwork and the striking board used to give it the correct shape. All the blades are struck out with the one template, which is moved from one position to another. After all the surfaces are struck out, the work being arranged so that they are finished by Saturday, fires are placed in the pit in the spaces between the blades, and the whole covered with sheet iron so that the fires may burn till Monday.

When thoroughly dry the bed is "black washed" with a mixture of charcoal and water, and the shape of the blade is drawn on from particulars on the drawing. Then the pattern maker prepares thickness strips from sections of the blade at different distances from the axis. They are approximately small segments of a circle of large radius, and are placed from 6 inches to 12 inches apart. The spaces between the strips are filled with loam, and the whole is smoothed off level with the strips, forming practically a propeller blade of loam. A large moulding box is placed over the loam blade; this is filled with loam in the same way as the top box of an ordinary mould is filled. The propeller boss is similarly "struck out" in loam, and from it the mould is taken. After removing the loam blades and boss and replacing the boxes, the mould, as far as the work of the striking board is concerned, is complete.

Moulding Machines.—New foundry appliances, especially those which tend to displace expert hand labour, are not readily taken up in the foundry. Still, one type of appliance, namely, the moulding machine, is rapidly increasing in favour. It follows, from the nature of the work which is of such great variety, that moulding machines cannot completely displace hand work. The previous example of striking board work shows that it would be anything but economical to design and equip a machine for moulding large propellers, which would only be used comparatively seldom.

There are several types of machine in use, and we may glance for a moment at their requirements and differences. They may be divided into machines which produce a mould from the whole pattern and those which only require a part pattern for the production of the complete mould. The latter type is used for the moulding of spur and bevel wheels, and require the attention of an expert moulder. When working with them great care must be taken that the pattern section is lifted truly vertically, and the rotation into new positions is accurately done. The former type, known as box moulding machines, merely produces the mould in a box in much the same way as in hand moulding, except that the sand is rammed mechanically. They are likely to replace hand moulding to a large extent, particularly when the pressing is done by compressed air or hydraulic power. The box moulding machine may be made as a "pulling-through" machine or as a "lifting-off" machine, with or without a swinging plate. Pulling-through machines are suitable for the more intricate work and for work of any depth, while the lifting-off machines are only

applicable to the simpler shapes of moderate depth. The use of the different machines is worthy of study; still, if the young engineer work in a foundry in which there are no moulding machines, he is not at a disadvantage, as he can, if he knows his work well, devise types for the different work himself.

Melting.—In brass foundries the metal is melted in crucibles which are heated in special crucible furnaces, while in the cast iron or iron foundry the cupola is invariably used. There is, however, an extending use of the regenerative furnace which previously had only been used for the melting of cast steel metal.

The cupola is practically a reproduction of the blast furnace (p. 26) to a smaller scale. The difference between the working of the two exists in the uninterrupted day and night working of the blast furnace, and the daily heating, charging and running down of the cupola. The following are some remarks on the cupola and regenerative furnace taken from an expert's views as given in "Stahl und Eisen":—

"The superiority of the cupola over the regenerative furnace is well known. We can, by its use, quickly melt large charges of pig iron with the smallest proportional amount of fuel, and with only little loss by oxidation. It requires no special form of skilled labour, and the first cost is comparatively small. It can, when necessary, be forced and overloaded, or it may be run with light charges; in fact, it accommodates itself to all the working claims put upon it. The regenerative furnace takes much longer to melt the charge, the loss by oxidation is greater, and experienced smelters are required to work it. The quantity of fuel required is also much greater than in the case of the cupola. In the cupola the weight of

coke necessary is 10 per cent. of the weight of the iron, while for the regenerative furnace the weight of coal required is 30 per cent. of the weight of iron. The difference is somewhat reduced by considering the cost of fuel, the coal being two-thirds the price of the foundry coke, so that the 30 per cent. of coal is equivalent in price to 20 per cent. of coke. All considerations lead us to the conclusion that the cupola is the better furnace for the usual grey castings."

The arrangement of the cupola with its fan, twyers and charging platform is to be well studied.

Selection of Iron.—The nature of the iron cast will vary from day to day according to the requirements of the engineer, and it is important to have a good knowledge of the choice and mixing of the various grades of pig iron to produce the required cast iron. The facts which are fundamental to the blending or mixing of pig iron are given in the previous chapter on materials of construction. Further, it is necessary to learn how the foreman estimates the amount of pig iron and scrap necessary for a single casting, and for the whole charge for one day; how the weight of fuel is determined, the blast regulated, and the melting of the metal in the cupola noted.

Casting.—The principal points to consider in casting are: the weight of the fluid iron; the fluidity; the separation of gas on cooling; and the contraction.

Pouring.—The weight of the fluid iron is a physical property which cannot be altered. It prevents, at times, the pouring of the metal directly from above, as the stream would strike the mould with sufficient force to destroy it. When such destruction is probable, the git is placed on one side of the mould and the metal is led from it through a passage in the sand

to the lower part of the mould. It will be obvious that all projections and cores must be made rigid and well fixed, to prevent the displacement which may be caused by pouring. The top box must be loaded with weights to prevent any separation at the common surface. If the corners and cores be not fixed as explained above, they float away on the surface of the molten metal, resting finally at the highest points, and produce bad castings, known as "wasters."

Wasters.—The production of wasters means a great loss to the iron founder because, in addition to the time spent on the mould, there are the re-melting of the metal, partial disorganisation of the work and often loss of valuable time in delivery. The English moulder suffers no loss for wasters, but probably is acquainted with the foreman's uncomplimentary opinions of him. In Germany, however, the moulder loses the value of his time spent on wasters, and in this way the loss is partly divided between master and man. This may seem hard, but when we consider a frequent cause of wasters noted above it will be admitted that the system is not unfair, and tends to a reduction in the number of wasters cast. The fact remains that in whatever foundry wasters are cast there will be unpleasantness. It may be added that lately the German moulder has insured himself against loss by wasters, which insurance is effected in several ways, but no results can be given as it has only been recently commenced.

Fusibility.—The fusibility of cast iron need not be the cause of wasters, as the fluidity can be increased in two ways. Firstly, the metal may be rendered more thinly fluid by raising the temperature to a point above that at which it melts. This raising of the temperature increases the consumption of fuel necessary,

makes the iron more strongly gas-absorbing, and causes more contraction when cooling takes place; two evils which must be combated by all means. Secondly, the iron may be made to melt at a lower temperature and to be more thinly fluid by a chemical process, and this consists of the proper choice of constituents. Phosphorus makes the iron more thinly fluid but also less hard. If the fluid iron is to be particularly thin for a single casting of intricate shape, a small piece of aluminium bronze is put into the ladle from which the iron is poured.

The necessary fluidity is required so that the metal may run into all the spaces of the mould, and to this end the designer should assist by making the corners well rounded and avoiding, as far as possible, parts which necessitate deep and narrow spaces in the mould. In this way any evil due to the want of fluidity is lessened.

Separation of Gas. — We come now to the most troublesome and often fatal properties of cast iron, namely, gas separation and contraction. If, through either of these things, the faults in the casting are apparent, it is a waster. If, however, there are faults and they are not apparent, the case is much worse, as, often after much time has been spent in machining in the workshop, blow-holes and flaws appear, and the casting, partly machined, is condemned. The worst case arises when the faults are not detected even when the machining is completed, and the casting breaks when at work, often causing loss of life and destruction of property. These considerations compel the moulder to strongly combat his two worst enemies (gas separation and contraction); and the greatest care is exercised, from the making of the mould to the delivery of

the casting, to prevent flaws or, if present, to detect them.

The molten iron is poured into the comparatively cold mould, cools in contact with the walls and solidifies. At times when the mould is moist the heat is quickly drawn from the outside layer of iron and a hard crust is formed. This hinders the escape of gas, and there is a danger of it remaining inside, making the iron spongy or full of "blow-holes." The making of a crust of this kind is sometimes desirable, as the quick cooling does not allow the carbon to separate from chemical combination, and a layer of hard white iron is the result. But certain precautions are to be taken, mentioned later, to prevent blow-holes. Such a casting is called a "chilled casting," and is made in a cast iron mould which has a thin coating of loam, the cast iron of the mould carrying the heat of the metal quickly away.

The molten metal can, by its porosity and the physical phenomenon known as osmose, allow the passage of the gas outside; so that, for some time after pouring, we can see small tongues of flame, due to the escape of gas. With large castings care must be taken that the gas comes from the top surface always. This is arranged by casting a very thick part, known as the "header," at the highest point of the mould. When the metal is poured it is stirred up by means of iron bars through the git, and this helps the removal of gas, or ensures that any which remains will collect in the header, and as this is broken away after cooling, it does not harm the casting.

Contraction.—All bodies expand when heated and contract when cooled, cast iron expanding about $\frac{1}{8}$ inch in every foot. It will be seen from this

figure that the contraction of cast iron is very important.

Contraction may be divided into two parts, firstly, contraction in the fluid state when the metal runs into all the spaces in the mould, and, secondly, contraction in the solid state.

The fluid contraction when filling or pouring is indicated by the sinking of the metal in the git, and when this is observed more metal must be poured. With large and intricate castings this after-filling may go on for some time, and in order to distribute the metal in the mould bars are moved about in the git and other openings. This pumping serves the additional purpose of keeping the metal more nearly fluid throughout and preventing the sinking of the parts which cool first from the sides of the mould.

Contraction in the solid state is the most difficult thing to cope with. It takes place in all parts of the casting, and the consequences, in addition to changes in size, must be considered. It has already been mentioned that pattern makers use scales which are specially made to allow for contraction; but this is not all. The contraction of the iron is not the same in all parts, being greater the longer the time taken to cool, and may be anything from 0·3 to 2 per cent. We know that an equal rate of cooling throughout is impossible, on account of the unavoidable hollow corners. In consequence of this some parts will contract while other parts are not in the state to contract, in just the same way as the one-sided warming of, say, a tumbler affects the glass. The side which is warmed expands while the cold side remains unchanged, and as both sides are connected there will be forces set up between the molecules of the body. If the heating be

sufficient the glass will be fractured, as often happens when hot water is poured into a tumbler or bottle. If different parts of the casting, owing to different thicknesses, cool at unequal rates, these forces will be present. They may be so small as to be unimportant, but, on the other hand they may be, and at times are, sufficiently large to cause fracture in the mould. Or they may not be large enough to produce fracture but approach the ultimate strength of the metal, in which case the casting will probably break during machining or while at work, owing to the internal forces being increased to just beyond the ultimate strength. Castings which have these internal forces are said to be initially strained or stressed, and every method must be employed to prevent them. All hollow corners must be rounded with large radii, and, as near as possible, the thickness should be the same in all parts, so that the casting shall cool at the same rate throughout. In cases where the designer's hands are, so to speak, bound, the moulder can greatly assist matters by freeing the comparatively thick and hot parts from sand. The cooling influence of the air then allows these parts to cool equally as quickly as the thinner parts which are buried in sand.

Dressing.—Finally, a few words in reference to dressing (cleaning the castings ready for delivery). The dresser has to cut away from the surface all projections such as the git, clean the surface of sand and remove cores from all holes. He must also pick out wasters, and his eyes must be well trained to pick out the often scarcely perceptible flaws. The difficulty and expenditure of time which may be given to various castings, in the removal of the cores, provide many lessons for the production of cores.

Although in the workshop the student is free—no doubt to his entire contentment—from the necessity of passing examinations for the information of his professors, it is none the less very desirable that he should be able to pass an examination for his own information, and with the object of bringing particularly to his attention some of the points which it is most important that he should observe, the following notes have been drawn up in the form of questions. It is not intended that anyone merely reading the book should attempt to answer them from information given in the text alone, but simply that his eyes and ears should have been kept sufficiently open during his work to make sure that he has observed enough to be able to answer them all, and, indeed, many other similar questions which are not put down, but which he can formulate for himself. The answer to the whole, systematically written out, might very well form the basis of the notebook which every young engineer makes for himself during his apprenticeship, and which a man often finds invaluable in his later career.

Observation Hints.

A. Pattern Shop.

For all patterns you see determine the following points: The number of parts; The reason for them; The scale used in making.

How is the correct position of the core in the mould assured?

How are loose pieces used for flanges, strips, etc.?

How do we make a curved surface of any kind in wood (teeth of wheels, propellers, etc.)?

How are hollow corners to be rounded, and what determines the amount?

For what purpose are the following woodworking tools used?

Firmer chisel,	Draw knife,	Jack plane,
Mortise chisel,	Cross-cut saw,	Smoothing plane,
Gouge,	Tenon saw,	Marking gauge,
Spokeshave,	Saw set,	Dividers,
Backsquare,	Bevel protractor,	Spirit level.

B. Foundry.

What means are adopted (apart from those given in the text) to make a casting of unequal thickness free from initial stress?

How does the core-maker stiffen the core?

How does the dresser know when all the sand is removed?

How does the moulder test the distance between core and mould, particularly when the walls of the mould are curved?

How is a casting, apparently good, tested for cracks and blow-holes?

What is the composition of the moulding sand generally used?

How does the foreman estimate the weight and cost of production of large castings?

What rule serves to determine the temperature of the metal when ready to pour?

How does the core-maker know when the core is sufficiently baked in the core oven?

How are the dovetailed grooves for a white metal lining prepared in the pattern, and how are they moulded?

What determines the position of the git, and what are the consequences of an incorrect position?

What is the object of drying green sand moulds?

What influence has position upon the good of the casting?

How are cored holes filled in the finished casting?

How much must the core be smaller than the finished hole?

What is the best position of cored holes for ease in moulding?

What do you understand by chilled castings?

When are core boxes unnecessary?

Why are ribs used in moulding boxes?

Why are rollers cast in a vertical position?

For what class of work are metal patterns used?

How can you tell, by inspecting the casting, the number of moulding boxes used?

CHAPTER V

FORGING

A. The Smithy.

THE importance of the foundry in an engineering works grows from year to year. This is due to the accomplishment of the process, the improvements in the properties of cast iron which approach those of wrought iron and steel, and the progress made in the making of special castings. On the contrary, forging is not applicable to this form of development, as it cannot be used for the cheap production of shaped bodies; unless used in conjunction with high speed steel machining.

The smithy attached to an engineering workshop is only suitable for the production of comparatively simple shapes. The manufacture of hollow forgings is continually beset by difficulties; they are on this account dearer than when made by casting. But the foundry invades the domain of the simple shape also, on account of the cheapness of production, especially when any supplementary work is necessary.

The forging for any required design is a rough and little exact shape, and if the finished size is to be quite clean, the thickness of metal left for machining must be fairly large. For example, the forging for a cross head must have at least a thickness of $\frac{1}{4}$ inch, for machining, all round, as the unevenness of the forged surface may reach this amount. This amount of material must be removed by machining, and is much

larger than the machining necessary for a casting. It follows then that the casting can be machined in less time than the forging; while it often happens that cast surfaces are so smooth that they may be used without machining. On the other hand, forged surfaces are so uneven and rough that they cannot be applied without first being machined. From these considerations we see that it is only profitable to employ forging for parts which are to be machined all over, which have the simplest form or shape possible, and which must be made of wrought iron or steel on account of the strength properties required. As an example which combines all three points we may take the crank shaft for an engine. The forging for this, with the exception of the crank webs, must be cylindrical, the webs being of rectangular cross section, so that the whole forging is combined of two simple shapes. The only metals suitable for this purpose are wrought iron and steel, each of which possesses great strength and ductility. Further, the forging compresses the metal, making it more dense, so that when it is put to work in the bearing it presents a good hard surface capable of resisting wear. Therefore all cranks used in an engineering works come, in the first instance, from the smithy.

A further cause which is displacing the smithy, to a certain extent, is the use of high speed tool steel for the production of simple shapes. By its use we can remove large thicknesses of metal from forgings and castings in a short time; and in fact, can do the work so cheaply, that many machine parts of circular section are now machined directly from the solid. As a striking example of the development of this work, we may say that a 2-inch round bar can be turned in the

lathe to a smaller diameter in less time than it can be forged to the same diameter. The turning is cheaper and has the advantage of producing a smooth and even surface. The forces brought into play in the application of high speed steel are continuous and much smaller than the periodic blows of the steam hammer. It is, in fact, the war between the rotating and reciprocating machines, another example of which is the case of the steam engine and steam turbine.

The principal thing which determines whether forging or turning will be cheapest, is the time; that which is quickest is cheapest. The greater the number of parts that can be turned out in a given time by any machine, the better employed is the capital which is invested in it, and the greater the return. Therefore the principal thing to aim at while at work in the smithy, is the capability of estimating the time necessary for forging. To this end the amount of work that can be done by the tools available, and the number of "heats" necessary, must be studied. In the exact cost comparisons there arise the different questions: What are the rates of wages for turner and smith? What amount of forging is necessary? How much turning can be done in the same time? What is the cost of the high speed lathe, and the steel necessary for it? How quickly does it wear out? How much coke does the smithy fire require? What are the working costs of the steam hammer? What is the value of economy of material (in the smithy no material is thrown away, while with turning a large weight of material is rendered useless, except for scrap, through being cut off)? Lastly, how long does it take per piece in the lathe and under the hammer?

The answers to these questions are only to be learnt by direct observation, and form the basis of cost estimating. They cannot be considered independently for general work, as the saving would not be equivalent to the time spent in acquiring the information; but for production in bulk, when the saving of a fraction of a penny on one piece is multiplied by thousands, they are important. For general work the time of production is the important factor, as the other things are more or less constant. It depends upon the nature of the work, whether it can be completely forged in one heat, or requires several, and whether it is easy or difficult to do, with or without special tools and contrivances. The observation must be directed to these things, and all facts should be noted in a book kept for the purpose. This will be found of great use later, at a time when it is discovered that everything cannot be carried in the head.

Hand Work.—The engineer should be conversant with hand work in the smithy, as it often happens that, when erecting machinery outside the works, a tool must be forged, or some other small job done, when no smith is available. It will be better to work in the tool smithy or on small work, than in the large smithy or forge. In the forge the pieces handled are so large that various mechanical devices are necessary, and the chief ability lies in the proper arrangement of the work, regulation of the appropriate heats, and avoiding waste by oxidation. The engineer must always leave this work to the foreman smith, who has the benefit of years of experience.

Welding.—As mentioned above, the engineer may, at times, have to make simple forgings, and these may include welds. Again, when designing he must have

a knowledge of the condition, cost, and strength of a weld ; so that this interesting and important process will be referred to, as far as the scientific explanation goes. It does not mean, however, that no time must be spent on welding in the smithy ; on the contrary, the whole of the work must be learnt by direct observation and actual practice.

In welding we bring the molecules of two bodies so closely together, and exclude all foreign matter to such an extent, that the cohesive forces which bind the single bodies into homogeneous masses also act between the two. Every surface, no matter how smoothly we grind it, appears rough and uneven under the microscope, and this unevenness would be much greater if the magnification were so great that we could see the molecules. So that when we put two such surfaces together they only touch at the tops of ridges ; adhesive forces are present, but not cohesive. To produce the necessary cohesive forces the surfaces are to be pressed closely together so that the uneven parts, so to speak, grip in each other.

To weld iron, both surfaces must be heated till they are glowing white and then pressed or hammered together. The weld is not successful unless we use a material which has large cohesive forces, *i.e.*, great ductility. Therefore the materials which can be welded are only wrought iron and the weaker (low percentage carbon) steels.

As we saw in the part on Materials of Construction, the percentage carbon influences the malleability and tenacity of the iron. In addition to this the iron combines with oxygen at the welding temperature, and leaves the surface with a coating of oxide. This will be found after heating, no matter how clean the

surfaces were before, if the metal has only the slightest contact with the oxygen of the air.

Welding Powder.—The only way to render the oxide or “hammer slag” harmless to the weld, is to ensure that the layer on the surfaces of the weld is thin fluid, so that it can be easily squeezed out when pressed or hammered. At the temperature necessary for welding (wrought iron, white heat; steel, bright yellow heat), the oxide is unfortunately hard and fast. On this account a powdered material is used which combines chemically with the oxide to form a fluid slag. This flux, or welding powder, consists chiefly of quartz in the form of pure sand. The process shows that the slag which is formed (exactly as in the blast furnace process) is more thinly fluid, the greater the number of different basic materials the flux contains. On this account the many mysterious welding powders contain besides: silicates, borax, potash, soda, common salt, sal ammoniac, fluorspar, manganese dioxide, and glass. Other mixtures follow, exactly as in the blast furnace process, the object of which is to combine with the oxide in such a way that it may be squeezed out when under the hammer. Further, in order to replace the carbon lost through oxidation, a stuff rich in carbon (potassium ferro-cyanide) is added in addition to the welding powder. This end may also be attained by heating in air-tight furnaces to protect from oxidation.

Special Welding Processes.—The various special welding processes are only distinguished from the original in the method of heating the metal up to the welding temperature. The oxy-hydrogen flame and electricity are chiefly used. The oxy-hydrogen flame heats the metal so quickly that the loss by oxidation is exceedingly small; while with the electric arc, or the method

which makes the metal itself the conductor, the heating takes place practically in the absence of air.

Another method, and one which is patented in all countries, is the chemical development of heat by Dr. Goldschmidt's "Thermite." Thermite is a mixture of iron oxide and finely divided aluminium, which can be set alight with a match. The combustion raises the temperature up to 3,000° C. (5,432° F.), and as the metal is embedded in the preparation, no injurious oxidation can take place. We may express the chemical change which takes place as follows:—

Aluminium + Iron oxide = Iron + Aluminium oxide.

The iron thus formed melts and forms a whole, together with the pieces to be welded, and as the metal is fluid, no hammering is necessary. Similarly the welding with "Blau" gas depends upon the reducing action of the constituents of the gas, and can produce a good weld, even when the surfaces were not previously cleaned. Here again, owing to the high temperature, no hammering is necessary. A knowledge of the chemical and physical explanations of welding is necessary, but not sufficient. In addition the engineer must learn the best form of surface for welding, the length and strength of hammering, cooling, etc.

We come now to the various contrivances used to facilitate the work in an up-to-date forge. The bending of rolled sections, wheel tyres, etc., is done exclusively by means of machinery; while the handling and working of large bars and ingots, as they leave the fire, are easily done by the aid of appropriate dies, cranes, etc.

Die Forgings.—Great progress has been made in late years in the manufacture of more or less intricate

forgings by means of dies and presses. This process is of great interest, not only because the work is lightened, but also because more intricate shapes may be manufactured from ductile material, instead of the more brittle cast iron. The only thing which limits the degree of intricacy is the capability of making suitable dies. The construction and cost of dies, as well as their effect on the manufacture, are to be noted.

Mechanical or Power Hammers.—The larger hammers are driven by steam pressure directly, while the smaller are invariably driven by air pressure, either directly, as in the case of small pneumatic hammers and the like, or in conjunction with a belt drive, as in the case of the so-called power hammers. The particulars or construction of these machines can be studied later, as they have no bearing upon smithy processes; but the handling and method of working should be observed. It has been stated that the driving method, whether it be by means of steam, air, spur gearing or belt, does not affect the processes; but if when working with these machines one is inclined to technicalities, it must not be forgotten that practical experience must always stand before theoretical deductions.

Presses.—The machines known as presses, by means of which a large amount of forging is done, are driven by water pressure. The pressure is produced by steam or electrically driven pumps; and the pressure water is delivered from the pump to an accumulator, in which it is stored until wanted. These hydraulic accumulators are not to be confounded with the electric accumulators or secondary batteries. The accumulator is placed between the force generator or pump and the force user or press; and its object is to store up large amounts of energy given spasmodically by the

pump, and give it out at a constant rate to the press. It consists of a cylinder fitted with a piston which is loaded with weights. As the pressure water is pumped in the weight is raised, and thus forms a store of energy which is given out again when the weight falls, owing to the water being taken by the press. The pump is automatically worked by the motion of the accumulator piston ; and the pressure used can be increased to any amount we please by increasing the weights, provided we do not exceed the safe pressure of the accumulator cylinder. The capacity of the accumulator should be sufficient to supply all the presses at one time ; and the pump must be capable of quickly refilling or recharging the accumulator.

The pressure on the pump, accumulator, and press, measured in pounds per square inch, will be the same according to the law of hydraulics ; so that the total pressure on the press will depend upon the area of its piston as well as the pressure. The total pressure on the forging will further depend upon the ratio between the areas of the press piston and press head. The triumphant course of the forging press is due to the unlimited possibilities which this method gives. It works without vibration and noise, and is applicable to a large number of forgings. The art of pressing has been brought to such a state of perfection to-day, that we may make forgings of exact dimensions from metal of enhanced value, owing to the beneficial effect of the pressing, without any waste of material. Further, the process is so easily performed that the expense of expert labour is eliminated. It is only necessary for the foreman to say how much metal is required to make exactly the desired forging. In this the art and great utility of pressing and die forging lie ; as any

superfluous metal has to be laboriously removed by machining. The difficulties of the method lie, not in the making of the forgings, but in the production of the dies, and the young man must have sound knowledge of their cost of production.

B. Boiler Shop.

Handwork is still further dispensed with in the boiler shop. It is confined solely to the placing of rivets in position, caulking of joints, and the drawing out or thinning of the edges of plates for certain parts of joints. Riveting is invariably done by machines, except in such places to which the machine is not accessible. This point should be remembered later when designing, and such places avoided. The thinning of plate edges is done in the planing machine, and any welding required would be done by Thermitite or with gas, etc. So that in large shops particularly, the work is almost entirely done by machines, although it will be seen from above that the necessity for handwork may occur at times.

Riveting.—The riveting will be better when done hot than when cold, and for the following reasons: The hot rivet is appreciably longer than when cold, owing to the expansion due to heat. It is put in place hot, and the head formed either by hammering or by machine; so that the plates through which it passes are held firmly together. As the body or shank cools, it contracts in length as well as diameter, and the plates are forced together with a great pressure, thus forming a good joint. This pressure due to contraction is absent when the rivet is worked cold, consequently the joint is not as tight as it would be otherwise.

Riveting Machines. — These machines are worked chiefly by water pressure, the smaller number being driven by compressed air. From the remarks above it will be seen that the rivet must not be formed too quickly. If this were done, any beneficial effect due to contraction would be neutralised by the yielding of the rivet head while still hot. The comparatively slow action of the hydraulic riveter is favourable to this end; and a further advantage is the cooling and hardening of the rivet head by allowing a small amount of the pressure water to come in contact with the hot metal. Riveting done by compressed air machines and hammering can be turned out as good, but requires more attention and patience. Another thing in favour of hydraulic riveting is the concentration of the energy of the machine on the rivet only; while in the case of compressed air and hand riveting the whole of the structure is shaken, and an external opposing pressure must be provided. In consequence of this the riveter is inclined to pass quickly over the work when done by hand or compressed air. Still, compressed air riveting machines are popular on account of their handiness.

Compressed air and hydraulic pressure have many applications in the boiler shop. Compressed air is much used for the so-called pneumatic tools, such as hammers, caulkers for caulking the riveted joints or seams, driving portable drilling machines and the like, and for hoists. Hydraulic pressure is used, as well as belting and spur gearing, for driving punching and shearing machines, bending and straightening machines, and for hoists and cranes. This class of work also provides a wide field for the electrical engineer—a fact which he is beginning to realise.

It is not the object of this book to describe in detail either the construction or the method of working of the various machines. The former can be learned during the University course, or with the aid of the books devoted to them; while the latter must be acquired by direct observation. Still, it may be remarked that in seeking for a connection between cause and effect, it must be remembered that as the men who work the machines are not experts, their technical knowledge is usually not sound.

Marking-off.—The young man should notice the large amount of attention given to the marking-off of plates, that is, the means taken by the marker-off to put marks on the plate where it is to be cut, drilled, punched or planed. This knowledge will be useful to the designer because, being quite clear about the scale, he will know how to instruct the marker-off. Notice the succession in which the marks are put on, and the method adopted to strike out curves of large radius.

Various Machines. — Drilling machines, especially those in which several drills work simultaneously (multiple drills), will be found in the boiler shop. Notice also the plate bending rolls for giving to the plates the required curvature, and the method of testing the curvature.

Tube work is a branch to which little attention is generally paid by young men; the extensive application of superheaters gives a special interest to this class of work. It must be noted how the tubes are bent, how the circular section is preserved during bending, and how the tubes are fastened into the walls of the superheater either by expanding or flanging.

The question of costs and their relations to one another can be more easily studied in the boiler shop

than elsewhere. One can take a watch in hand and see how long it takes to put in a row of 100 rivets, to caulk a joint of certain length, or to drill 50 holes of a given diameter and depth. Further, notice the time taken in preparation of the work for machining, marking-off, erection, etc.

Constructional Ironwork.—This is a branch of work which is very much the same in principle as boiler making, as it consists in the building together of a structure from rolled sections by means of rivets and bolts. The work turned out is larger than that from the boiler shop and necessitates greater preparations for marking-off and more time for erection and re-erection. There also arises the question of building up parts that will not be too large for transport on the railway.

C. Tool Smithy and Hardening.

It has already been mentioned that the tool smithy is the best place in which to acquire a knowledge and skill in handwork. It has the further advantage of familiarising the young man with a large number of tools that are used, as well as the properties of the materials from which they are made. It often happens that in addition to the tool smithy there is a hardening room or smithy, and when this is the case the apprentice should always have access to the latter during his smithy training. Both places are connected, even when machine parts are hardened in addition to tools. The practical side of the hardening process cannot be given in detail on account of the innumerable artifices involved, but some facts are given in the following.

Object of Hardening.—The object of hardening is two-fold. Firstly, it reduces the amount of wearing of



rubbing surfaces, consequently hardened surfaces will be found in many machines, a well-known example being balls for ball bearings. Secondly, the hardening makes steel hard enough to penetrate various metals and to cut chips off, as in the case of lathe tools, etc. We see, from the application of tools, that a material which has been hardened must also have great strength. Therefore, for good hardening, the process should be carried out so that it shall have the least ill-effect upon the strength and elasticity of the metal. Such hardening cannot be attempted with the mild steels such as Bessemer and Siemens-Martin, but only with the better quality steels such as cementation and special tool steels. The metal should have a homogeneous structure, and is better new than old. Crucible steel is best for tools, but, being made only in small quantities and by comparatively few makers, it is costly. It costs about sixpence per pound, while the special steels may cost as much as three shillings per pound. In spite of the high prices these steels are always used, as they make tools which last longer and are more economical. The capacity of a machine is increased by using high quality steel, it being much better employed when the worker can go straight on, instead of having to stop to sharpen the tool about every fifteen minutes, and when he is not afraid that it will become heated and soften. It will be seen then that first-class material is economical in the end in spite of the extra cost of working. Again, experienced tool smiths and hardeners can develop the usefulness of a steel to an extent that would not be possible in works not so well equipped. Therefore in a well-arranged works it will be found that great attention has been paid to the laying out of tool smithy and hardening room.

Theory of Hardening.—The cause of hardness or hardening is simply explained. The hardness depends upon the amount of carbon which is chemically combined, and which we may call solution or hardening carbon. Now iron (we may refer to the metal as iron) is a solvent of carbon, and its solvent properties increase with the temperature just as in the case of water. Consequently fluid iron can contain a fairly large amount of carbon in solution, and this amount decreases as the temperature falls. As we saw in the case of pig iron, the carbon which is thrown out of solution by cooling exists as a mechanical mixture of graphite. The whole of the carbon does not separate out in this way; in fact, in the case of wrought iron the total carbon is so small in amount that it remains in solution, even when cold. Again, any surplus carbon which tends to separate on cooling is prevented doing so if manganese be present. The manganese atom gives to carbon the capability of chemically combining with iron, even down to a temperature of 700°C . ($1,292^{\circ}\text{F}$.), and the carbide Fe_3C is formed. Thus manganese pig iron will contain one molecule of iron and solution carbon for each molecule of iron carbide. The molecules are arranged in two intercepting networks and possess great strength; but on account of the interception of the nets the metal is brittle as well as hard.

The separation of solution carbon on cooling takes an appreciable time. If the necessary time be not permitted, and the cooling takes place quickly, then we have (as far as the influence of cooling goes, and, for success, this must be done quickly) a homogeneous structure of iron and solution carbon. This molecule possesses great strength, and its presence is the cause of hardness. If, on the other hand, the cooling pro-

cess be comparatively long, the formation of carbide commences and increases with time of cooling. The greater the total amount of carbon in the iron the greater will be the percentage solution carbon after sudden cooling, and the greater the hardness of the iron. It is thus possible to take the total percentage carbon as a measure of the hardening capabilities of iron.

These facts may be briefly expressed as follows :—

Pig iron, containing very little or no manganese (grey, soft pig) ; hardening carbon greater than 2·6 per cent. When cooled the surplus carbon separates out as graphite.

Manganese pig iron (white, hard pig) ; hardening carbon greater than 2·6 per cent. When cooled the surplus carbon combines to form iron carbide.

Steel ; hardening carbon 0·5 to 2·3 per cent. When slowly cooled the surplus carbon becomes partly graphite and partly carbide, and the steel is comparatively weak. When suddenly cooled all or nearly all the carbon remains in solution, while a little may become carbide, and the steel is extremely hard.

Wrought iron ; hardening carbon less than 0·5 per cent. When cooled either quickly or slowly all the carbon remains in solution, as there is no surplus.

It follows that the only metal we deal with in hardening processes is steel, and this is harder, but at the same time more brittle, the greater the percentage of hardening carbon present. In addition to the above hardness, which we may call chemical, there is another we may call mechanical, brought about as follows: The cooling of the steel is more sudden on the outside layers than at the core or inside, consequently the outer layers contract the most and, compressing the core, give it an undesirable hardness.

At the same time the initial strain reduces the elasticity of the steel, and makes it brittle.

We see, then, that a simple heating of the steel, followed by sudden cooling in water, cannot produce useful hardness. The steel certainly becomes very hard—so-called “glass hard”—but is much too brittle for use in the majority of cases. On this account we must resort to “tempering” processes to remove a part of the brittleness. After hardening the steel is heated to a temperature, below that at which it glows, varying from 200° to 330° C. (393° to 626° F.). In this way part of the solution carbon is thrown out and becomes carbide, thus reducing the hardness, but also increasing the elasticity. This supplementary heating also causes the pressure of the outside layer to be removed, thus reducing the brittleness.

Hardening.—We will briefly consider the steps in hardening. The tool or other forging is heated up to the correct hardening temperature. This changes with the quality of the steel and the object for which the tool is designed. Generally speaking, the hardening will be more efficient the greater the temperature drop when cooling takes place. There is a limit to this drop, however, as it is proportional to the contraction of the outside layers, and this may be so great (if care be not taken) that the outside fibres are torn. This danger must, of course, be always avoided.

Temperatures and Glowing Colours.—The hardening temperature of steel is less than the temperature necessary for forging, both of which temperatures are known by the colour with which the hot metal glows. Steel begins to glow when the temperature is between 500° and 600° C. (932° and 1,112° F.), at which point it resembles dark brown autumn foliage. Increasing

the temperature above this point the colours succeed as follows:—

Dark cherry red at a temperature of	..	800° C. (1,472° F.)
Light „ „ „ „	..	900° C. (1,652° F.)
Yellow red „ „ „	..	1,000° C. (1,832° F.)
Yellow „ „ „	1,000° to 1,200° C.	(1,832° to 2,192° F.)
Dull white „ „ „	1,200° to 1,300° C.	(2,192° to 2,372° F.)
Brilliant white „ „ „	1,500° to 1,600° C.	(2,732° to 3,092° F.)

at which temperature the melting point is reached.

The hardening temperature lies between 700° and 800° C. (1,292° and 1,472° F.), or the temperature at which the red glow commences. When the whole of the metal has this temperature the compression of the core by the outer layers has the same beneficial effect as forging or pressing, and the strength and elasticity of the steel are increased.

Annealing.—In certain cases it is economical to use the forging heat as hardening heat also. The tool is forged at a yellow heat and then gradually cools to the hardening temperature (dark cherry red), when it is suddenly cooled. For good work this is not permissible, as there is a risk that the tool will be bent and distorted. This is due to the fact that initial strains are set up in the steel during forging, owing to the bending and working of the metal. Such strains must therefore be removed before hardening, and this is done by annealing. The steel is packed in wood charcoal to restore carbon to the outer layers, which have already lost carbon by oxidation during heating for forging. The whole is packed in a box to prevent further oxidation, and heated to a dull red heat. The mass is then allowed to cool, and it is important that the heating and cooling take place gradually, so that the temperatures at different places in the steel shall be

the same at one time. If this point were not attended to, the initial strains would remain. It follows that the more intricate the forging the more important is the annealing. After annealing, the forging is heated up to the hardening temperature; and if there are any parts which are not to be hardened they are protected from the heat by a coating of loam.

Cooling.—The cooling must be done rapidly and in such a way that internal strains, due to unequal cooling, are avoided. The means employed to ensure regular and equal cooling must be noted. The rapidity of cooling depends upon the following properties of the hardening fluid: the initial temperature, the capacity for heat, the heat it absorbs (latent heat) to form vapour, the time taken to reach the boiling point, and the specific gravity. They must all have attention paid to them when determining the quality and amount of hardening fluid. It will not be possible to discuss these matters fully, but a few particulars relating to the hardening fluids which are commonly used are given below.

Hardening Fluids.—Water is generally used as hardening fluid, and it is squirted with a syringe, or the tool is dipped or immersed in it. Solutions of common salt, sal ammoniac, nitric acid, or sulphuric acid (2 to 4 per cent.) augment the hardening properties of water; while solutions of lime, soap, gum, or spirits lessen them. Another hardening fluid much used is oil. It has been found that oil abstracts the heat more equally from all parts of the tool than does water, and for this reason it is used for the more important work. It may be mentioned, further, that the hardening influence of oil is not as great as water.

Several of the more easily fluid metals are used as

hardening fluids when the degree of hardness required is not great. They are molten tin 230° C. (446° F.), molten lead 330° C. (626° F.), and molten zinc 400° C. (752° F.).

Testing of Hardness.—After cooling, the hardness of the steel must be tested before tempering is proceeded with. This is invariably done by trying a file on the surface; if no scratch be made, then the steel is said to be “glass-hard.”

Tempering.—The surface of the hardened tool has the layer of oxide removed from it; that is, it is polished by rubbing with sandstone or in any other way desirable. This is done so that the various colours of the oxide films may be readily distinguished. The tool is warmed, when the following colours will be seen on the polished surface; they follow each other in the order given, and give us an exact measure of the various temperatures:—

<i>Light yellow at a temperature of 220° to 230° C. (428° to 446° F.)</i>		
Dark yellow	„	240° C. (464° F.)
Brown yellow	„	255° C. (491° F.)
Brown red	„	265° C. (509° F.)
Purple	„	275° C. (527° F.)
Red blue	„	285° C. (545° F.)
<i>Cornflower blue</i>	„	295° C. (563° F.)
Light blue	„	315° C. (599° F.)
Grey blue	„	330° C. (626° F.)

The various colours are due to the reflection and refraction of the light by the thin film of oxide which forms on the polished surface of the tool. They are known in physics as “the colours of thin films”; another example being the colours seen when paraffin oil is thrown on water.

If we take the temperature as indicated by the colour, and assume that the whole tool has the same

temperature, then careful and slow warming is necessary, otherwise the assumption is not justified. This slow warming also serves to remove any internal strains which may exist.

The higher the temperature of tempering the less hard and more elastic will the steel be, and this fact enables us to lay down rules connecting the colour of tempering and the work for which the tool is to be used.

The blue colour must be reached before cooling out tools which have to be tough or ductile enough to withstand shocks without having the cutting edge chipped or broken (chisels).

The red colours are to be used for machine tools which, while capable of withstanding great pressures steadily applied, must also have sharp and durable cutting edges (lathe tools).

The yellow, commonly called straw, colours are for all tools which are to take a very fine edge which must also be durable (wood chisels).

When the requisite colour is reached, the tool must be suddenly cooled to prevent the temperature rising further. The tool is thus hardened and tempered, and only requires grinding to become ready for use.

Working with One Heat.—For the less important hand tools such as chisels, it is possible to harden and temper with the one heat. The tool is first heated to the hardening temperature, and cooled for a short time till the surface is cold. It is then rubbed with sandstone at the place where the colours are to show, and these follow as the heat from inside is conducted to the surface. If a chisel is being hardened it may be heated to the hardening temperature for one half of its length. The point is cooled out and rubbed with

sandstone and the colours appear as the heat from the uncooled part is conducted to the point. There is a great risk of internal strains and unequal temper with this method, owing to the different temperatures throughout the steel when it is cooled. Still, a man who is expert in this class of work can turn out good, durable, and well-tempered tools.

Machining Hardened Steel.—The hardening (hardening and tempering) of tools and forgings is done before the body has its finished shape. It is machined before hardening till only a small amount of metal remains to be removed, this being left on account of the warping or change which may occur. The final working or machining is done after hardening, in a way that is almost self-evident on account of the nature of the material. It will be clear that it cannot be done in the usual manner by means of tool steel, as the tool, although it is as hard as the steel, cannot cut. The only process remaining is grinding, and this is done with the small corundum and carborundum wheels, as these materials are harder than hardened steel.

It would be possible to harden the rough forging and then machine completely by grinding, but this is not desirable, especially in the case of more intricate shapes. It is not for any want of excellence in the work of the grinding machine, as they have been very highly developed of late years; but the grinding may remove the hardened surface, or, if the hardness runs throughout the whole material, the removal of the outer layers frees the core from certain strains, and in consequence the body may be warped.

Case-hardening.—Steel being harder than iron, it is more difficult to machine. Thus if we could, by any means, machine an iron body, and then convert it

to steel to be hardened, the work would be done more cheaply and quickly. This method is used for many machine parts which require hardened surfaces, and it is known as case-hardening. The surface is first machined to almost the finishing point, and is then heated in contact with some material rich in carbon. The hot metal takes up carbon from the material covering it, and in this way the surface of the metal has its percentage of carbon increased. Thus the outside layer is converted into steel to a depth which depends upon the material used and the time of heating. If, after heating as explained, the body be cooled out, the surface is hardened and may be ground to the finished size. Any parts which are not to be hardened are covered with loam as previously described. If the process were carried to extremes, the body would be packed in a material rich in carbon, and after heating for several days, would become wholly steel, as in the cementation process.

The practical details of the process are to be learnt by direct observation ; but the cause of the change is the materials used to give carbon to the iron. They consist of mixtures of various organic (carbon-containing) substances and inorganic substances, and in many places are jealously guarded as great secrets. The materials used for the mixtures are : salt, glass, sal ammoniac, wood charcoal, gum arabic, brick dust, chalk, rye meal, resin, horn shavings, Peruvian bark, potassium ferro-cyanide, potassium nitrate, clay, saw-dust, glue, urine, etc.

The young man should, while in the hardening room, acquire a knowledge of the shapes which are in least danger of being cracked or distorted by hardening. It will be found of use later when designing, and

he will then be able to reduce the number of wasters and expensive hardening processes to a minimum.

Observation Hints.

Estimate the weights of all forgings and compare with the actual weights.

In what way is the straining of iron bad ?

What is the bending test for good wrought iron ?

What is the average loss by oxidation in the smithy fire ?

Is it possible to weld together two different kinds of iron (*e.g.*, iron and steel) ; and if possible, what precautions are necessary ?

What is the object of such a weld as above ?

How does the burnt or oxidised iron appear on the hot and cold metal ?

How can you tell that a surface is ready to weld ?

What are the evidences of good or bad riveting and caulking ?

How is accurate drilling done with a portable drill ?

What are the advantages and disadvantages of punching and drilling rivet holes ?

Riveting and expanding boiler tubes ?

Machine- and hand-riveting ?

How is the circular section of a tube maintained during bending ?

How accurately can a tube be bent in more than one plane ; and how often must it be tried or fitted before completion ? How can the same bends be obtained when using steam pipe fittings ?

What is the relation between the costs of the two last processes ?

In how far does the water test on a boiler give us an idea of the working capabilities ?

What facts must be considered, having regard to transport difficulties, in the design and erection of large iron structures?

What means are employed to put the "finishing touches" to hardened steel bodies?

How would a hole be made in a large forging, and when is drilling cheaper?

How can hardness be tested other than with the file?

What is the lowest heat possible for forging?

What is the effect upon the iron when the forging is done in the cold state?

What is the effect of repeated hardening and tempering upon steel?

What is the object of the following tools?—

Flat tongs.	Spike or stock.	Planishing hammer.
Round tongs.	Two-beaked anvil.	
Gas tongs.	Stock anvil.	Round set hammer.
Pin tongs.	Filing block.	
Wire cutters.	Hatchet stake.	Ball hammer.
Nippers.	Bordering tool.	Chasing hammer.
Pincers.	Round-head stake.	
Nail pullers.	Polishing plate.	Panining hammer.
Forming pliers.	Swage block.	Drift.
Dogs.	Flat hammer.	Pick hammer.
Bench shears.	Straight peen	Top swage.
Frame shears.	sledge.	Mallet.
Shears for holes.	Sledge.	Set or chisel.
Wire shears.	Pointed hammer.	Hot and cold set.
Fire hook.	Cold chisel.	Poker.
Cross-cut chisel.	Hollow punch.	Rake.
Die.	Plate gauge.	Punch (hand and bench).
Hole gauge.	Cross peen hammer.	
Beak of anvil.		Punching pliers.
Beak iron.	Ball peen hammer.	Wire gauge.

CHAPTER VI

THE MACHINE SHOP

A. General.

ALL progress that has been made in the manufacture of engineering materials, rolled sections, finished fittings and castings, has only become possible by the development of machine tools. We would not to-day be in the position of having the advantages of finished fittings, were it not for the progress made in the machine shop in the last few years. This development in engineering, as in everything else, depends naturally upon the progress made in the manufacture of raw material. The present-day machine tool, well made and highly efficient, would not be so efficient if the universally used high speed tool steel were not made. Thus it will be seen that the machine shop is, so to speak, the high school of practical training, from two points of view. Firstly, the young man can acquire a knowledge of the refined methods of measuring and working—methods which are so different from those formerly used. Secondly, he comes into actual contact with machines expressly designed for the accurate machining of all kinds of engine parts.

An exhaustive description of the machines and processes employed in the modern machine shop will not be given here, for two very good reasons. The description would be too long and tedious to read, and then it is in no way intended to replace knowledge gained by direct observation.

The work of the machine shop must be regarded from two points of view: namely, the class of work suitable for each machine, and the design of the engine part or article considered.

It is easy to manufacture high class engines with the present-day materials and machine tools; but there may be a difficulty in making them cheap as well as highly efficient. The key to the solution lies in the capabilities of machine work, as cheaper machining must stand for greater return upon capital outlay. On this account the work must be suited to the machines as much as possible; and no machine must be allowed to stand idle, as, no matter how complete it may be, it cannot earn anything when standing. The work must be divided proportionately amongst all the machines, so that they are kept continually going; and in this organisation lies the art of the shop foreman.

It may be supposed that the shape of the article is decided by the designer's knowledge of the working of the engine. This, however, is not sufficient, as the designer must know, just as well as the shop foreman, what machine is most suitable for doing the work cheaply. He should be able to picture the whole of the processes involved, and the order in which the operations are carried out. This knowledge can only be gained by actual work and observation, and will be of great use to the young man in later years.

Setting.—The first process through which a casting or forging must pass after it leaves the marking-off table and is ready for machining, is "setting." This consists of attaching it to the plate or table of the machine in which the work is to be done. The transport of the casting, which must be done cheaply and efficiently, depends upon the engineer who builds the

workshop and the shop foreman, but the setting depends greatly upon the designer, as will be seen from the following. If the casting be subjected to large forces when being machined, then great care must be taken that sufficient surface is provided for contact between itself and the machine table, so that there may be no relative motion. Then it must be supported in such a way that the forces due to the bolts used for attachment neither fracture nor distort it. If any temporary changes of shape are caused in this way the surface, which was machined correctly in the constrained position, will be warped when taken out of the machine. This, it will be seen, is only what we can expect from the elastic properties possessed by the materials used for castings and forgings. Thus a cylinder which is bored out truly circular would be more or less elliptical or oval when taken out. The designer must therefore remember these facts, and should make his design so that the casting may be easily set in the machine; and, if necessary, make provision for the holes of holding-bolts and the like. In fact, he must ensure that the necessary setting shall be done as easily and quickly as possible, from which it follows that the usual devices and methods adopted in setting are of great importance.

Jigs for Setting.—Any contrivance used to facilitate machine work is known as a “jig.” When possible, castings are set by means of the simplest of fastenings, special bolts and plates being made and used for the purpose. They are used when only a small number of the same kind of casting is to be machined, and are too simple to be called jigs. But when large quantities are to be handled, or the setting is more difficult, a special contrivance or “jig” is made. Its design

requires an exact knowledge of the working processes through which the article must pass, and probably will only be finally decided after consultation with all the workmen interested. If we decide upon the use of a jig we do all that is possible to lighten and hasten the work. In fact, jigs are so productive of good results, that they are built for castings and forgings that can be set very well without them. The thing we have in mind when considering questions of this kind is the time taken for setting, during which the machine is standing. There are many unclear notions about this point, and people differ in their estimates of the correct percentage of total working time to be allowed for setting and taking down. The young man should therefore take every opportunity of observing skilful workmen, and, when possible, noting the time taken for setting and taking down. The result will probably be a very high percentage of the total time, and will do more than anything else to emphasise the importance of adapting the design to render setting easy; it will further show the effect of jigs upon good and economical work. He must endeavour to learn how much cheaper the work is done by means of jigs than previously; and notice that in addition to reducing the amount of work necessary, the risk of error is less when jigs are used. In this way he learns to appreciate the high value of jigs when used correctly, and thus pays proper attention to the peculiarly shaped boxes and frames which might otherwise remain unnoticed.

High Speed.—The consideration of the economical procedure already noticed in connection with jigs leads us to ask: What can we do further to simplify and cheapen the work? The first answer that is suggested

to us is that concerned with the increasing of the speed of working to the highest possible value. But the higher limit of speed is quickly attained, being dependent entirely upon the inevitable heating of the tool and casting, due to the work done on the metal, and to the friction. As it is not practicable to measure the temperature at the point of the tool when working, we must keep on the safe side by keeping the working speed well below the highest possible. The heating takes the temper out of the tool, rendering it unfit for use, and also has a bad effect on the casting, owing to the consequent expansion. The casting is rigidly fastened to the table of the machine, and in such places the expansion is resisted, internal strains and stresses being set up. At places sufficiently far from the table the expansion is unresisted and the casting is warped. The consequence of this is that when the surface, which was truly machined when hot, cools, it is no longer true or exact, on account of the disappearance of the expansion. If the surface is untrue by an amount greater than 0.005 inch, to which degree of accuracy machine work is done to-day, the casting will be a waster, unless it is possible to remove the error by further machining.

Cooling.—It would be an easy matter to prevent the heating of the tool by using a stream of water to carry away the heat; but there would be great danger of destroying the steel of which the tool is made, as by a temporary suspension of the water supply the steel would heat up, to be suddenly cooled out again when the water supply was restored. Thus the tool would become very hard and brittle, and would soon reach the point at which fracture would occur. This danger could be avoided by using a fluid not possessed of such

great hardening properties as water. We have already seen, in the previous part, that an addition of soap reduces the hardening influence of water. In fact, a saturated solution of soap and water has practically no hardening influence, and this cheap method of cooling is used on nearly all machines. The soapy water performs another function, as it lubricates the cutting edges and surfaces. If these surfaces were dry, they would quickly heat up and wear away; but when the soapy water is applied, a thin layer of it is formed between the tool and the casting, owing to the physical phenomenon known as capillarity. This hinders the contact of metal and metal, and thus prevents wearing away. If the cut be light or of small depth, there will be very little heat to be conducted away, and then the layer of soapy water prevents the immediate pressure of the neighbouring surfaces of the tool. Thus a cause of roughness is removed, and a beautifully smooth and bright surface is the result.

All methods used for the dripping of soapy water upon the cutting edge of the tool are of importance. For the deeper cuts and tougher materials it must be noticed that the fluid is circulated by means of small centrifugal pumps, which draw the supply from a receiver in the base of the machine. After use, the fluid runs back to the receiver, and is allowed to cool before being used again. This is another instance of the striving for greatest possible efficiency which is so characteristic of the present-day machine shop.

Cutting Capacity.—If by cooling, as above, we may approach more closely to the speed at which dangerous heating occurs, the limit will then be decided by the cutting capacity, or the amount of material that can be removed in a given time. It depends upon the

following three quantities :—Firstly, the speed of cut, or the length of the strip of metal removed in one minute. Secondly, the feed, or the distance the tool moves in passing from one cutting position to the next. Thirdly, the depth of cut, or the thickness of the strip removed. These sizes should not be taken from the strip which is removed, as the metal is distorted when cut ; but by the difference between the sizes of the work before and after the cut. The volume of metal removed in one minute is given by multiplying together cutting speed (length), feed (width), and depth of cut (thickness). With the usual good tool steel these quantities may have the following values for wrought iron :—

Speed of cut	.	.	18 feet per minute.
Feed	.	.	0.06 inch.
Depth of cut	.	.	$\frac{1}{4}$ inch.

Thus the volume removed per minute is :—

$$18 \times 12 \times 0.06 \times 0.25 = 3.24 \text{ cubic inches.}$$

The weight of this is :—

$$3.24 \times 0.277 = 0.897 \text{ lb.}$$

Therefore in one hour the weight removed will be :—

$$60 \times 0.897 = 53.8 \text{ lbs.}$$

When this amount of material is removed per hour, or the cutting capacity is the same, the cutting edge of the tool attains a temperature of about 220° C. (428° F.) and this in spite of all cooling. This fact is evident from the steam which rises from the cutting edge. Now as the tool is tempered at a temperature of 220° C. (428° F.), it is evident that this will limit the cutting capacity.

High Speed Steel.—The cutting capacity of the tool can only be increased by using for its manufacture, a steel which may be heated, to a temperature above 220° C., without becoming soft. Such steel was first introduced in the year 1880, and although not perfect, was much used. Since that time a large amount of experimental work has been done in the endeavour to attain perfection, with the result that to-day the high speed tool steel, as it is called, is the most important factor in economical working. It has completely revolutionised machine shop practice, a fact which is evident from the comparison of the present-day machines with those of twenty or thirty years ago. Such steel can be heated up to a temperature of 500° C. (932° F.) without affecting the hardness; and when it is remembered that the metal begins to glow at this temperature, we cannot do other than look upon such an achievement with wonder and admiration. This property of the steel is due to the presence of chromium and tungsten, which elements give to the steel a great capability of dissolving hardening carbon, and at the same time prevent the formation of carbide.

With the best class of high speed steel we may reach a cutting capacity which is seventeen times that of ordinary tool steel; but for average values we must take it to be four or five times that for tool steel. This large increase in cutting capacity tells us why it is more economical to use high speed steel, although it is about six times the price of tool steel, and can only be used in powerful machines which are specially designed for its use.

Tool Grinding.—The smoothness and speed of the cut is much influenced by the condition of the tool, and, to a great extent, this depends upon the machinist

in charge of the machine. The piece-work system compels the man to take an interest in his work, and to see that the tool is correctly tempered, ground, and set in the machine. It will be worn out more quickly if not in the correct position, even if it be made of special steel. Thus it will be seen that in a well organised workshop, in which all refinements are adopted, the care of the tool, as far as tempering, grinding, and setting are concerned, will be taken from the machinist and put into the hands of an expert. This warrants a department specially devoted to tool-making, in which expert tool-makers grind all the tools in specially designed and accurate grinding-machines. By means of scientific experiment the correct cutting angles, for the majority of cases which occur, have been determined. The angle between the front and top of the tool, and that between the top and side, are so important for good work, and the deviation that is permissible from the standard values is so small, that even the most experienced turner cannot get them right "by the eye." The laws which determine the angles cannot be discussed here, but must be left for the university or technical school training. The young man should, however, question the machinist and tool-makers about their tools, as the explanations he receives from them will go far towards helping him to understand the scientific theories.

There are many exact cutting shapes and angles, and these are standardised in the form of gauges, from which the grinder mechanically makes the right shape. This is another example of the displacing of expert hand work by more exact mechanical methods.

Another thing which is no less important to the tool than grinding, is its hardness. In the part on

“hardening,” it is shown to what extent this depends upon the capabilities of the workman, and the appliances he has at hand. For this reason the present practice is to have the hardening done in a special department, instead of each machinist doing his own as was previously the case.

The setting of the tool in the machine is important, as referred to above, and the young man should notice that experienced men devote a little time to this. Experiments have been made with different forms of tool-holder, with a view to designing one which will not depend upon the skill of the workman, but be automatic; up to the present, however, nothing successful has been produced. From these remarks it will be seen that it is economical to have a row of machines tended by unskilled men, provided the tools are set by one skilled tool-maker.

Turnings, Chips, etc.—The working properties of the material which is being machined have a great influence upon the wear and tear of the tool, as well as upon the straining or stressing of the machine. The harder and more brittle the metal, the quicker will the cutting edge be blunted, and the more slowly must the machining be done. The speed of working will be different in different cases, and for general work the correct values are given in a table at the end of this chapter. Cast steel must be worked at a speed which is only from one-tenth to one-twentieth that for copper, and from one-fifth to one-tenth that for wrought iron. We can determine the correct speed when we know the strength properties of the material. The formation of turnings and chips (the small pieces of metal removed in machining) gives us an idea of the behaviour of the metal, while their appearance indicates the strength properties.

The difference between the crumbly cast iron chips, the long tough curls of wrought iron and steel, and the short, bent chips of copper alloys, are readily apparent to everybody. But an experienced man may, by an inspection of them, give an estimate of the strength, elastic, and hardness properties of the metal, which, when compared with the result of scientific experiment, will be found to be fairly accurate. In fact many practical men determine the strength in this way, without recourse to experiment. Thus it will be seen that the apprentice who uses his "eyes" and "brain" will, by spending a little time in the study of turnings, chips, etc., acquire much valuable knowledge.

"Practicable Shapes."—In the choice of material the engineer must have regard to the strength properties; the working in the raw state (casting, forging, rolling, etc.); the possibilities of economical machining, and the machines used. Complete regard to the correct kind of machining is only possible in the department of what we might call "practicable shapes," and their construction. It is fundamental to all construction, and must be left to the theoretical training for complete treatment. Even then it is difficult to understand; but the young man who takes his workshop training before the theoretical, has the great advantage of a knowledge of practical requirements. Assisted by his knowledge of success and failure he will be able to correctly appreciate the value of such training.

Referring to the properties of bodies and shapes which are most important, we must first learn that any deviation, however small, from the simple shapes and simple motions, causes a great amount of complication. We must, therefore, adhere to the simple shapes—*i.e.*, the right angle, the straight line, and the circular

section—unless there are important reasons to do otherwise. If the alternative be chosen, we must observe what change in the machine is necessary before the work can be completed; what additional appliances and difficult measurements are rendered necessary. For example, we might take the case of a wedge having an acute angle, or the turning of a conical surface in the lathe. More intricate shapes, such as prismatic bodies with curved bases, require special appliances (shaped milling-cutters, templates, etc.); while machine-cut gear-wheels and worms require intricate machines of special design for their manufacture; and bodies of elliptical cross-section require special lathes.

On the other hand there are some intricate shapes, such as helical or screw surfaces, which can be easily made in the normal machine. The screw surface is a combination of simple circular motion and simple straight line motion; and it is well known that these may be obtained either singly, or combined, in the normal lathe. Thus the helical surface is “simple” as far as manufacture goes; and in all construction “simplicity” must be the keynote. The young man must, therefore, be able to determine whether a shape is simple or intricate, in a workshop sense—that is, whether it can be machined easily or not; and it is in this sense that the expression “practicable shape” must be understood.

The experienced engineer only thinks of, and designs simple practicable shapes; and this important connection between shape and the method of its production separates the engineer’s ideas of shape from those of the painter and architect, who are only governed by “style.” In this matter one is only conscious of

harmony by a contemplation of the whole work ; and the engineer's training is such that the appearance of the completed engine or machine is also harmonious. It may be called the æstheticism of practicable engineering shapes ; it needs no rule of "style," as it is itself full of style.

Another thing with which the young engineer should be familiar, when commencing his theoretical training, is the origin of the shapes he sees in the completed engine. In this connection it is instructive to reflect upon the finished parts which he may see lying about the machine shop ; the way they are fastened in the machines, and the way in which the shape they possess is given to them. They are to be found mostly in the neighbourhood of the machines concerned in their manufacture ; he may see what method of working has been employed, and whether any part of the work has been left uncompleted, etc. Facilities of this kind offered by the practical training are of great value.

Working of Machines.—It is important to observe the simple means adopted by machinists to save time and increase the efficiency of the machines. Particular mention may be made of starting levers, packing pieces, and chalk marks for determining the extent of the travel. These contrivances are connected with a very important part of the work—namely, the handling or working of the machine. This depends chiefly upon the development of the personal skill and intelligence, as the machinist is in sole charge. Still, it is the duty of the foreman to see that the man is complete master of the machine before he is allowed to work it. The more intricate and developed the machine is, the greater is the influence of good or careless working

upon faultless and quick work. Thus, in addition to making the man familiar with the machine he works, it seems desirable to introduce some system of remuneration which will compel him to also take good care of his machine and method of working. It is only in a workshop organised in this way that good work can be turned out cheaply.

When the apprentice first works in the machine shop he will be put on a machine which is anything but new, intricate, and highly developed. The work he turns out from it will not be of high value; but that is not an important point. He is not put there to turn out good work, so much as to acquire experience; and this latter will be of high value, if he is enthusiastic. He will learn how to take care of various mechanisms, and the usefulness of different arrangements. He will also learn to know each machine as a particular object with particular faults and particular humours; and will do well to notice which parts require oiling, and which do not; how the necessary oil is applied, etc. Such observation and training will be found useful as helping towards the "engineering instinct," as well as enabling him to work the modern machines.

Erection.—In addition to acquiring a knowledge of and skill in machine work, the young man should be present during the erection of engines, machines, etc. The finished parts ready for erection may be seen in all parts of the erecting shop ready for preliminary erection, and are worthy of inspection both before and after. Important work is erected before being sent out, even if it has to be taken down for delivery. A good example of erection is afforded by a machine tool which combines exact fittings and parts with the most careful erection; great care must be taken that the

foundations do not sink, the frame is not initially distorted, and so on. The ways these things are tested are to be carefully observed by the young man, who will thus develop his knowledge of construction. The knowledge of the requirements of parts which fit together will be increased, so that when a new machine begins work he will be quite clear about the object of each part. The erection of machine tools, already referred to, is the most instructive example, as the new machines can be compared with the older types about the workshop, and a picture of the development of shape, towards perfection, is obtained. It will therefore be seen that when the erection of machine tools is going on, the young man should ask to be allowed to take part in the work. In fact, if the work is being carried out at some place distant from the works, a few days' leave should be obtained.

Accuracy.—The great advantage of the experience referred to above is the definite ideas it gives about the degree of accuracy to which we must work, and to which we can work, in the case of such erections. By the use of accurate spirit levels, squares and straight-edges, we are made to appreciate the great difficulties caused by any change of shape in the bed or parts of the engine or machine, due to erection, or to the forces brought into play when set to work. In short, we become acquainted with all the difficulties incident to present-day machine and engine building.

The accuracy of the engineer's machine is absolutely the greatest point for combining the present day high speed working with accuracy of the work turned out. Of course a clever machinist can do exact work on an inaccurate and shaky machine, and it is very probable that most of the readers of this book will have to do

their preliminary work on machines of this kind. Still good work can be turned out ; but even then the most expert machinist takes more time and can more easily produce wasters, than the average workman on a faultless machine. This accuracy of the machine increases its first cost ; but without it, the high speed of working (with special steel) would not be possible ; and as the increased speed more than compensates for the extra initial cost, it will be readily seen that the accurate machine is most economical.

The principal points to be noted for accuracy in machines, are: perfectly plane (flat) surfaces ; rigid support to the tool ; accurate motion of the part to be machined ; elimination of "back-lash" (slackness between parts which move over one another, such as screws and nuts, etc.); correct alignment of all spindles and journals ; all edges truly rectangular ; and equal distance between all parts of parallel surfaces.

The accuracy with which the work is measured is closely connected with the accuracy of the machine, and is of such importance that the connection between the two is considered in a particular part later.

The last important point to be considered in connection with the economical manufacture of engine and machine parts, is the allotting to each machine only that work for which it is particularly suited. A few remarks on this subject are given below, with the types of machines.

B. Types of Machines.

Review.—The common object of all machines is the removal of chips from the surface of metal, and in order that this may be done, there must be relative motion of tool and work continually. In this motion

either both, or the tool, or the work, may move, and the motion may be linear or circular, in vertical or horizontal planes.

It would be impossible to deal with all the machines found in the modern machine shop, but the chief types are noted later; and it must not be forgotten that the aim is to direct the young man who is about to come into contact with many unknown machines. Further, the classification is neither to be taken as exhaustive nor yet strictly scientific.

We may divide machines into two chief classes: those in which the work (machine part to be machined) moves, and those in which the tool moves. In the case of the lathe the work revolves while at the same time the tool moves in a direction perpendicular to the direction of motion of the work. Thus there are two motions; but as the former is much greater than the latter (in one revolution of the work the surface travels a distance equal to the circumference, while the motion or "feed" of the tool seldom exceeds 0.2 inch), and the greater motion being understood in the classification, the lathe belongs to the first class. There is still another class in which both the tool and work have large motions, and the whole three classes may be again subdivided according as the motion is circular or rectilinear. Thus the various machines are given in the table on p. 130 in a way that will assist the young man in forming definite ideas of them after he has started work in the machine shop.

A glance at the table shows that in the majority of cases the circular motion is used; and after a little time has been spent in the machine shop the young man will notice that every effort is made to do the work by means of rotary motion. The question of

130 WORKSHOP MACHINES AND PROCESSES

circular or rectilinear motion is most important in machine work, and is dealt with later in considering the contest for supremacy between the planing machine and the milling machine.

At the end of this chapter two tables are given which show the loading capacity and the power required for

TABLE OF MACHINES CLASSIFIED ACCORDING TO THEIR MOTIONS.

Motion.	Axis or direction.	The work moves.	The tool moves.	Both move.
Circular.	Horizontal axis.	Lathes.	Universal milling machine, horizontal boring machine, circular saw, grinding machine.	Special milling machines, grinding machine.
	Vertical axis.	Boring and turning mills.	Drilling machine, vertical milling machine.	Special milling machines.
Rectilinear.	Horizontal direction.	Planing machine.	Shaping machine.	—
	Vertical direction.	—	Slotting machine.	—
		Many examples of wheel-cutting and worm-hobbing machines.		

various machines. They are given without further explanation; and as a certain amount of theoretical knowledge is necessary for their understanding, they are more suitable for those who have already spent some time in the university or technical school. Still, they are not useless to the beginner, who may,

by having regard to the observation hints, study them with profit, and he is directed to devote any leisure hour to the understanding of all the numbers given.

1. The Lathe.

The lathe was the first machine ever used in an engineer's workshop, and was formerly driven by the muscular force of the operator or turner. Many of the smaller lathes to-day are driven by means of the treadle, and it may be the young man's lot to work such a machine. It is absolutely universal, being more useful than any other single machine. Nearly all machine parts, whether they have flat or curved surfaces, can be machined in it. On account of the large variety of work which can be done in it, the lathe must be worked by an expert machinist. This is necessary on account of the intricate changes necessary in the machine for different classes of work. From these facts it will be seen that the training of the young man in lathe work or turning is of the greatest importance to all classes of machine work. This fact is often recognised by the workshop foreman, but in a way which does a certain amount of harm, as the young man is, unfortunately, often kept at the lathe during the whole of his workshop training. This, of course, is not right, and endeavours should be made to spend a large amount of the time on the lathe, and the remainder, working on other machines.

The three principal processes in turning are : turning, boring, and facing.

Turning.—By turning we understand the removal of metal from the outside curved surface of the work. The simplest example is that of a purely cylindrical body, when the work rotates and the tool moves in a

straight line parallel to the axis of rotation. Such work is most convenient, and is rapidly done; but when conical, spherical, and specially-shaped surfaces are required, the time of working increases rapidly. In the latter cases special tools are required, from which it will be seen that the work must revolve more slowly than for simple or plain turning.

Screw-cutting.—A particular kind of turning is screw-cutting, or the making of screws in the screw-cutting lathe, and this cannot be adopted too often, if done rationally. By means of this the designer can ensure that the work is done cheaply; but only when the changes of wheels and tools necessary are reduced to a minimum; and this is only possible when he thoroughly understands the process of screw-cutting.

The beginner often has a difficulty in understanding the relation between the pitch of the screw, the pitch of the leading or guide screw, and the ratio between the wheels used. In this respect help may be obtained from any elementary book on applied mechanics, and this, combined with the explanation of the turner, should be sufficient to make the whole matter clear.

Boring.—By boring we understand the machining of the inside parts of hollow bodies. The designer must always have in view the cost and difficulty of neat boring; things which are not apparent on the drawing. If a hollow space of any kind is to be "bored out," it can only be done by a tool which passes through the front hole, and this hole must be large enough, not only to admit the tool, but also to allow any lateral motion necessary for the machining. When the hole or space is of great length, it is not sufficient that the tool be supported at one end only, and provision must be made for the use of a boring bar.

Facing.—By facing we understand the machining of flat surfaces in the lathe. It will be clear that the tool must move in a direction perpendicular to the axis of rotation, and the metal is removed in rings of different diameters. If the revolutions of the work remain constant, then as the diameter of the circle or ring increases (owing to the motion of the tool away from the axis), the speed of cut will also increase. Now a low cutting speed is uneconomical, while a very high speed is dangerous, not only to the tool, but to the work as well. We endeavour to do the whole of the machining at the highest safe speed by varying the number of revolutions. This is done on large lathes either by a gradual change or stepped changes, in an automatic manner, and any loss of economy is thus avoided.

Surfaces are only to be machined in the lathe when they are circular rings of comparatively narrow breadth; for other surfaces special machines are to be used as they do the work more economically.

Special Lathes.—Owing to the large variety of turned work which is required in present-day engineering practice, there are many lathes specially built to do one class of work. They are in many respects different from the ordinary workshop lathe, still it requires no imagination to see that they are lathes. One example to be found in large shops is the shaft lathe for turning long shafts. The bed or gantry is of great length, and is provided with supports to prevent the work bending during machining. For the machining of short circular bodies of large diameter wheel and facing lathes are used, while for large flywheels the special lathe used is vastly different from the ordinary lathe.

Turret Lathes.—The value of time in the economical machining of all parts is of greatest importance, so

that a lathe which is so constructed that all the work may be done without taking out and changing tools, is an acquisition. This is accomplished in the turret lathe, in which provision is made for the housing or fitting in of several tools, usually six, at one time. They are fitted into holes, made to receive them, in the turret head, and are brought into use alternately by swinging or turning the turret head through the requisite angle. The tools can be set in place by an expert turner or tool maker instead of by an unskilled machinist, and further economy results. It is obvious that a tool is more universal, the simpler it is, and when it is applied for one purpose only as in the turret lathe. It follows, then, that the design of engine parts that have to be machined in turret lathes offers many examples for the exercise of practical knowledge. As an example, the manufacture of any part in a turret lathe carrying six tools can be easily and cheaply done as long as no more than six tools are necessary for the complete machining. If a seventh tool be needed, then the necessity for a change of tool arises, and the economical working is affected to a much greater extent than would be the case for an angular change of the turret head only. These are the points which are to be noted in a correct estimation of lathe work, and they can only be understood and appreciated by actual work on the machines.

Automatic Machines. — The last step in the development of lathes towards economy of time and attention was made when the automatic machine was invented. It is a form of lathe, not in appearance, but in the work it does (turning, boring and screwing of every description). It might also be called a combination of man and machine, as, when it is correctly set, and the bar

of raw material once inserted, it goes on machining the required parts, throwing them when finished into a tray or other receptacle. All processes after the insertion of the bar (the machining with separate tools, changing of tools, cutting off finished part, changing of rough bar into another position for another part to be machined), are all purely automatic, and one experienced man may attend to as many as twenty machines. The speed of working is raised to the highest possible limit, only possible by the great attention paid to the cooling and lubrication, which is done by a constant stream of oil directed to the cutting edge by means of centrifugal pumps. The mechanism of these machines is necessarily most intricate, and it would be hopeless for the young man to attempt to understand it in the workshop; such study must be left to the university and technical school courses.

2. Boring and Turning Mills.

These machines comprise the horizontal boring machine, and the vertical turning and boring mills. In the horizontal boring machine the work is stationary, while the tool revolves, and at the same time is fed or moved along, as the metal is removed. In appearance it is nothing like the ordinary lathe, the principal part being the boring bar and head, which are supported at the ends in a suitable manner. The boring head carries the tools or cutters, and is advanced along the bar as well as rotated with it. A portable form of this machine is used in the portable boring machine. It consists of a boring bar and head with suitable supporting gear to be attached to the large engine cylinder or other part, which it machines in place.

The vertical boring and turning mills are practically

lathes with vertical axes, the design being adapted to the vertical position. In the boring mill the work revolves while the tool is stationary. It has a great advantage over the ordinary lathe for large work, as, during setting, the casting or forging merely rests upon the plate, and has not to be supported in any way. It also possesses the advantages of the turret lathe because a number of tools may be used, as they are at rest when cutting. When more than one hole is to be bored in the one casting, a new setting is necessary for each, and on this account it compares unfavourably with the drilling machine, in which the toolholder can be made to move in any direction. Thus, for this class of work, the boring mill is uneconomical.

In the turning mill the tool has a much larger motion than in the boring mill, especially in a horizontal direction, the work revolving. It has therefore all the advantages of the boring mill, and, on account of the horizontal motion of the tool, is particularly useful for the machining of large flat surfaces.

3. Planing and Slotting Machines.

Both planing and slotting machines have straight line motion, but while in the planing machine the work moves, in the slotting machine the tool moves. They thus appear to be in a position to fill a want not supplied by lathes: namely, in the machining of large flat surfaces. During the whole of the forward or cutting stroke, it would appear that the speed of cut is the same; but we will see that this is not the case, and that all other machines are more economical than planing and slotting machines. In fact, all machines with straight line reciprocating motion retain certain fundamental disadvantages.

Planing or Milling?—The principal evil to be noticed with all these machines is, that the machine does no useful work throughout one half of the motion. This is exactly the case of the planing of a piece of wood by a joiner, from which process the machine gets its name. At the end of the working stroke, when the cut is just completed, the tool has to be drawn back, without cutting, to be ready for the next cutting stroke. There have been many attempts to overcome this disadvantage. Tool-holders of special shape have been designed for the forward and backward strokes, with the object of working all the time. Many ingenious reversing arrangements using electro-magnets, and springs, have been devised; but in spite of all this work, the fundamental disadvantages are not yet surmounted. Now in all reciprocating machines, the forces necessary for the motion are completely changed in direction when the motion is changed. As a consequence of the shaking caused by these changes, the slides, upon which the table moves, suffer. Thus the principal advantage of the planing machine, namely, accurate work, is lost, on account of the unavoidable play or backlash in the slides.

The great point to be considered in determining whether the work is economical or not, is the time taken for its completion. On this account there is another way in which the use of planing and slotting machines may be made more economical, namely, the running of the backward non-working stroke at a higher speed than the forward stroke. In new machines the speed of the backward stroke is often four times that of the forward stroke. This, however, is not altogether good, as the change in speed, together with the change in direction, increases the wear of all

parts, particularly the belting and wheels. In consequence of this the return on the capital invested in such machines is smaller than in the case of machines with continuous motion. This is the reason for the entrance of milling machines into the field, which was, until recently, exclusively held by planing and slotting machines.

A further disadvantage of all reciprocating machines is the small range of speed available for cutting different metals; also the speed during the cutting stroke varies at places, as the change in the direction of motion can only take place gradually. On the other hand there are several points in which the planing machine has the advantage over the milling machine. The cost of the tool for the planer is very small compared with the cost of the milling cutter; and as the cutter has much more surface than the tool, it stands in greater danger of warping by heat. Still, this danger can be entirely avoided by the careful use of soapy water, as referred to previously. The actual prices of the tools for milling and planing machines are not a sure guide to the economical advantages, as will be seen. The price of a milling cutter weighing ten pounds would be about thirty shillings, while the same weight of planer tools would cost about twenty shillings. The weight of the latter would be much less than ten pounds in order to do the same work as the milling cutter; and its cost for hardening, tempering and grinding about half that for the cutter. But the durability of the single cutting edge of the planer tool cannot be compared with the numerous cutting edges of the cutter; consequently the former will wear out much sooner and will have to be taken out and prepared, perhaps six times, to once

for the cutter. Again, any error in the angle given to the tool reduces the economy, while the cutter can only be ground in a machine, and must necessarily have the correct cutting angle. Thus the milling cutter can always be worked economically at the highest possible speed, and, all things considered, is cheaper than the planer tool.

There are surfaces, however, which are more economically machined in the planer, and these are long, narrow surfaces, and surfaces of large width. The former would be distorted by the heavy pressure of the cutter, while the manufacture of a wide cutter for the latter is unsatisfactory owing to hardening difficulties (the greater the width of cutter the greater the thickness for the necessary rigidity, and this causes unsatisfactory hardening). Above the upper limit of width, determined by these facts, the planer is exclusively used, as there is no relation between the size of the tool and the extent of the surface.

In addition to these considerations there is the important one of keeping all machines going, and this will probably account for the fact that work is sometimes done in the planer that could be more cheaply done in the milling machine.

4. Milling Machines.

From the previous remarks under the head of "Planing and Slotting Machines," it will readily be seen that the milling machine has great claims upon the most careful observation of the young engineer.

Milling Cutters.—We may, as an illustration, look upon the milling cutter as a circular file (revolving on a spindle), with very deep grooves, or very high teeth. In this way it is more easy to understand how the

machine replaces hand-work. The better thing for comparison is the cutter-head of a boring machine, as this exists in practice, while a rotating file does not. In this head a number of steel knives or cutters are fixed, all radiating from the centre of the shaft. If they are carefully inserted, so that the distance of the cutting edge from the centre of the shaft is the same for each, then on rotation of the shaft each edge describes the same circle. If such an arrangement with, say, six cutters, be put to work upon a surface, it will remove much more material in one revolution than would a cutter-head which only carried one cutter. It will not remove six times as much material, nor will it wear out six times as slowly, as the single cutter-head. These things depend upon many factors, but chiefly on the correct insertion of the cutters. The patience and time necessary for the fitting of the cutters is very great, and they tend to neutralise any advantage due to the arrangement. On this account cutters and head are made in one piece, and the tool thus formed is called a milling cutter. It can only be ground in a special machine, and this, as explained before, is an advantage.

Cylindrical and End Milling Cutters.—It is natural that from the development of the milling cutter, it is capable of a greater variety of work than the cutter-head above. Its chief work is the machining of flat surfaces, and these may be done in either of two ways: the axis about which the cutter rotates may be parallel to the surface, when a cylindrical cutter is used; or the axis may be perpendicular to the surface, when an end or facing cutter is used. Both processes may be carried out in the same machine either singly or together, as in the case of slot-cutting (the bottom of

the slot is done with the cylindrical part of the cutter, while the sides are done with the end faces). Considering the two cutters separately, however, it is important to learn for what class of work each is suitable. The great disadvantage of the end-cutter is, that the circumference moves at a greater speed than any other point, while the centre does not move at all. The wear and tear is therefore unequal, being greatest at the circumference. Still, as the end cutter is not related in size to the size of the surface, while the cylindrical cutter must have a width equal to that of the surface it machines, the end cutter is cheaper in this respect.

Formed or Profile Milling Cutters.—The end or facing cutter can obviously be used only for flat surfaces, and can therefore not be applied to the class of work which is so advantageous to cylindrical cutters. This work, namely, the machining of shaped surfaces, is very common in engineering practice. If, instead of a straight cutting edge, the cutter be given a formed or profiled edge, then when it is rotated in contact with metal, the surface generated will be the negative of the profile of the cutter, which we here regard as the positive. It will be readily seen that, being provided with a correctly shaped cutter, the saving of time is enormous compared with any other method of working. Further, the high degree of accuracy attainable is in no way a disadvantage to economical work. But the greater the effect the greater the expense, and in this case the great expense is in the manufacture of the cutter. The making of such a cutter requires special machinery and expert labour, and the expense involved is only justified when repetition work is to be done—such work as gantrys for lathes and the like, and

particularly for the machining of the teeth of spur and worm wheels. A set of wheels, such as the change wheels for a lathe, having to gear all together, may be cut with one and the same cutter. In addition to the accurate shape of the teeth, the pitch must be correct, and this is ensured by the use of the "dividing plate," to which the observation should be particularly directed.

A method of constructing profile cutters which is simple and yet interesting, consists in building them up from simple cutters. A number of these, which may be standardised, are made to fit the same spindle, when by using them in different arrangements, different profiles may be obtained. This is merely an imitation of the principle involved in the building of houses of different shapes, from the one kind of brick. The use of this kind of profile cutter is economical for single articles; but only when the shape is suitable, and this depends upon the design.

Backed-off Cutters.—The manufacture of profile cutters has greatly enhanced the value of milling machine work, but there is still room for further improvement. If the ordinary cutter be ground, and its shape altered ever so little, this will be sufficient to render the work inaccurate. This is particularly objectionable in the machining of wheel teeth, in which absolutely no error is permissible. Thus the necessity of the backed-off cutter arose before profile work could be largely employed. The work is done in a special lathe, and the cutter thus made may be ground without having the profile altered. The backing-off of cutters is so advantageous that ordinary simple cutters are made in this way. The cutters or teeth are stronger, and the cutting angle is always the same.

The particulars relating to backed-off cutters and the lathes in which they are machined are well worthy of special attention while in the workshop.

Circular Milling.—A development of profile milling which is to-day a great acquisition, is circular milling. Circular bodies of special shape, such as hand wheels and the like, can be machined in the miller in much less time than in the lathe.

Finally, there are special milling machines for doing copying work. They require special contrivances, and are only used for production in bulk or numbers. Any advantage or disadvantage of milling machines is connected with the accuracy of the work or the rate of working, and these points require special attention.

5. Drilling Machines.

Drilling and Facing. — The method of working employed in the drilling machine is very much the same as that in the process of end milling. It is not in any way restricted to the boring of holes, a large amount of work being done in the facing of flanges, and surfaces which are perpendicular to the axis of the drill. The work is invariably done by means of a boring bar and cutters, but if the surface be small a specially-shaped drill is used.

Reamering.—A question of greatest importance is the degree of accuracy attainable in the drilling machine. The holes as bored or drilled in the machine are not accurate enough for "fits," and require to be reamed after leaving the machine. This consists in finishing the hole by means of a reamer, a tool which we may look upon as a particular form of cylindrical milling cutter. On account of the cutting angle used, and the small taper, there is a great

tendency to "seize," or become fast, in the hole, and the use of a reamer therefore requires a certain amount of skill.

Arrangement of Holes.—Another important point upon which the economy of drilling depends is the arrangement of the holes. It will often be found that a hole required in some part of a casting cannot be drilled in the machine, and must be done by hand. Such a hole is often to be drilled, and for this reason various appliances are always at hand to do the work. But cases may arise in which the ordinary hand gear is not suitable, and special appliances have to be made. Again, holes that are to contain studs, and must consequently be tapped, must be in such places that they can be tapped, drilled, and the stud driven in place. The determination of the easy or difficult drilling of a hole is a thing which can only be learned by actual practice, and the young man is directed to pay great attention to it, or he will, in later years, very easily design holes which can only be drilled by hand, or perhaps not at all.

Drilling Jigs.—Attention is directed to the various appliances used on the drilling machine, templates, setting plates, parallel vice, etc.

Particular Types of Drilling Machines.—For the majority of holes of small size, the ordinary vertical pillar machine may be used. It is made as a single-gear machine, with hand feed, to run at high speed, and is then usually known as a "sensitive drill." The heavier machine is double-gear with hand and power feed, and may be used for boring bar work as well as the drilling of large holes.

If the casting or forging is to be secured and a number of holes drilled, the "radial drill" is the

most convenient tool to use, as the drill may be moved into different positions for the one setting of the work. This machine is made double-gearred with hand and power feed, and is the most useful drilling machine made.

For the drilling of rivet holes in rows or circles, the multiple spindle drilling machine is used, in which a number of drills are used simultaneously. They are made as vertical machines to drill a row of holes, and as horizontal machines to drill a circle or ring of holes.

Many holes, chiefly rivet holes, can only be drilled in place, that is when the whole machine or structure is erected, and therefore cannot be done in the vertical or radial machines. These necessitate the use of some form of portable machine, of which there are many examples. They are driven chiefly by compressed air and electricity, and may be regarded as hand-drilling gears with pneumatic or electric motors added. In such machines, the fundamental fault of all drilling machines, namely, the uncertain guidance of the tool or drill, is most pronounced. In order to overcome this difficulty as much as possible, and to work quickly, all the drills for one machine are made to fit into an ingenious drill socket. The uncertainty is further lessened by having a well-defined "centre dab" (small hole into which the point of the drill is placed), as the greatest difficulty is experienced when starting the hole. Deep centre dabs are not advisable, as they take time to make, and if not in the right place are difficult to correct; consequently the designer should, when possible, have the surface to be drilled perpendicular to the axis of the hole. In this way a large amount of time, necessary to start the hole if the surface and axis be not perpendicular, is saved.

6. Grinding Machines.

The grinding machine is the latest addition to the list of machine shop tools, and was designed to supply a necessity in the working of glass-hard surfaces. Such surfaces must possess the greatest strength and hardness, and consequently cannot be machined in the lathe and similar machines. The machine work may be done before hardening, but we have already seen that the hardening process produces internal strains and alters the shape of the body. It follows then that it is impossible to complete the machining before hardening, and, after hardening, to have the same size, with bright and smooth surfaces. So that we are compelled to leave a small layer of metal after machining in the lathe, milling machine, etc., and to have this finally removed and polished after hardening. The machine in which this work is done must have two properties, namely, its tool must be harder than the hardest steel, and the work it does must be as accurate as that turned out from the best of lathes.

These properties are possessed by present-day machines to such an extent that, for some time, they have only been used to remove layers of metal which are considerably less than $\frac{1}{100}$ inch in thickness. Such machines are used not only for hardened steel, but also for the naturally hard steel and iron; the cutting capacity is equal to that of good steel, while the finish is often better.

Method of Working.—This depends upon the following fact. The steel tool works with a great force and proportionately low speed of cut, and as the work progresses, it leaves a furrow with raised edges. When the crests and hollows of the wave line of this furrow

section are only measurable in thousandths of an inch, as is usually the case, the surface is considered accurate. On the other hand the grindstone works with a small force, but with a cutting speed equal to that of an express train. The broad stone running quickly over the work removes a very thin layer, or we may say membrane, at each revolution. The turner may easily cut too deeply into the metal; but the grindstone cannot do this, and only approaches the limiting size gradually, the very fine layers being removed one after another. The consequence of this is that the grinder can very easily stop the work at any point when the required amount of metal is removed. In general working each point in the circumference or surface of the work is brought into contact with the stone three or four times. At the first contact the greatest amount of metal is removed; at the second a smaller amount; and so on. Thus the roughness left after each contact is removed by the next; till, after the stone and work have been in contact several times, the surface is highly polished and accurate.

Emery Wheels.—This triumph of the high speed circular tool is naturally combined with disadvantages which, more or less, tend to affect the economy of the process. The greatest lies in the manufacture of the tool used; that is the emery wheel. They are made either of the natural emery, or the artificial carborundum. The latter is a carbide of silicon, and is produced in an electro-thermal manner: made in the form of a more or less fine meal (depending upon the refinement of the work to be done), mixed with a gummy or sticky substance, and subjected to a great pressure in moulds of the correct shape. The wheels thus made are of all sizes and fineness, from the very

small fine wheel used by dentists, to the large coarse wheel used to dress castings and do all kinds of rough work. An idea of the prices will be gathered from the following : Carborundum wheel, 2 inches diameter and $\frac{1}{2}$ inch wide, 2s. ; 4 inches diameter and 1 inch wide, 5s. 6d. ; the largest wheels, 20 inches diameter and 4 inches wide, £20.

Wet Grinding.—Further disadvantages which must be attended to are the generation of heat and dust, which are present in large quantities. They are rendered unobjectionable by the use of water ; and as there is no danger of the tool softening with heat and hardening again when the water is applied, it is not necessary to mix soap with it. A small amount of soda may be added to the water, as this lessens the tendency to rust. If the grinding be done dry, the dust, which is very injurious to the health and to the machine itself, is removed by special suction fans. It is clear that any machine which is to turn out accurate work, must itself be most accurately made. The accuracy may be present in the new grinding machine, but if the dust, from the wheels, which contains a large amount of emery or carborundum, is allowed to get into the bearings and other working parts, they are quickly made inaccurate owing to the grinding action. This is the reason for the special constructions adopted for the different kinds of grinding machine.

Finally, in determining shapes which can be machined by grinding, all sections having re-entrant angles or curves are to be avoided, as well as sections made up of limited curves.

Observation Hints.**a. Turning Shop.**

What do you understand by centring ?

What depth of centre is necessary ?

The turner may remove the last $\frac{1}{1000}$ inch with the file ; can this be done without injury to the circular shape of the section ?

What means are employed to prevent the bending of long shafts and the like ?

Can a casting already bored, be put back in the lathe and turned so that outside and inside are truly co-axial ?

How can you determine whether a template is bent or not ?

What change in the loose headstock is necessary to turn slightly taper ?

What is the effect on the work when the spindle of the fast headstock is parallel to, but not in the centre of, the gantry ?

What are the numbers of teeth in the largest and smallest change wheels ?

What are the uses of the following tools and appliances ?

Angle plates,	Flat drills,	Outside chaser,
Slot plates,	Boring bars,	Screw-cutting
Hook bolts,	Face plates,	head,
Square centres,	Dog chucks,	Swinging tool box,
Pipe centres,	Mandrels,	Screw gauges,
Hollow centres,	Expanding man-	Centre grinder,
Knife tools,	drels,	Drivers,
Parting-off tools,	Centre stays,	Carriers,
Milling tools,	Centre drill,	Lathe gaps.
Roughing tools,	Inside chaser,	

U O P B

b. Planing, Shaping and Slotting.

What contrivances are there for use in the machining of concave and convex cylindrical surfaces, such as reversing gear links?

What appliances are necessary for the shaping of spur and bevel wheels?

What amount of clearance is necessary when the tool works up to an end face?

How is the travel of the machine varied?

How is any "backlash" in the slides taken up?

How is the taper provided for when slotting a keyway?

Why is the tool holder made to swing on a hinge?

How do we determine the correct angle for planing two surfaces which meet?

What are the advantages and disadvantages of simple and built up tools?

What are the principal plates and fastenings used on planing, shaping and slotting machines?

What is the use of the parallel vice?

c. Milling Machines.

How are wedges milled?

How are grooves and feather ways milled?

How is a hexagon nut milled?

How are spur, bevel and worm wheels hobbled?

What is the smallest radius to which a concave surface may be milled?

How are twist drills milled?

What is the use of the dividing plate or head?

How are gauges used in the milling of spur wheels?

How are clutch couplings milled?

How is the axis regulated when bevel wheels are milled?

BY THE

What is the use of the following tools and appliances?

Built-up milling cutters,	Surface gauge,	Parallel vice,
Backed-off cutters,	Cylindrical cutters,	End mills,
Side cutters,	Face cutters,	Gear cutters
Slot cutters,	Worm hobs,	Hollow mills,
	Profile cutters,	Double cutters.

d. Drilling Machines.

What happens if we attempt to drill a hole where two different materials join?

What is the best form of drill to use for the above hole for accurate work?

If the axis of the hole be oblique to the surface, how do we start it?

What length of hole, compared with the diameter, can be drilled with the ordinary flat-pointed drill?

What do we use for the drilling of longer holes?

What is the chief difficulty experienced in drilling very long holes?

How do we ensure that the drill will not run sideways when drilling a long hole?

How does the designer mark on the drawing the kind of drill to be used?

What is the influence of the different kinds of drills upon the accuracy of drilled holes?

How is the position of a hole defined or marked by the marker-off?

How are boring bars guided and the cutters fixed in place?

If the drill tends to run in the wrong place, how does the driller correct the work?

What is the disadvantage of drilling a hole which does not run through, compared with one which runs through?

10-11-14

What size of drill is necessary for a hole that is to be tapped for a 1 inch thread ?

How are drills of different sizes fitted into the one machine ?

What are the uses of the following tools and appliances ?

Machine reamers,	Boring bars and	Ratchet braces,
Flat-pointed drills,	cutters,	Hand drill,
Twist drills,	Breast drill,	Drill socket,
Rose bits,	Swan neck or	Roundnose chisel,
Pin drills,	drill stand,	V blocks.
Countersink,	Tapping head,	

e. Grinding Machines.

How are twist drills ground ?

How are milling cutters ground ?

How are spherical surfaces ground ?

How is grinding done to template ?

How are large rolls ground ?

What appliances are used for polishing ?

What are the different forms of socket used to hold the work ?

What is the use of the diamond and holder ?

How are polishing wheels made ?

What is the use of the magnetic clutch ?

How are balls ground ?

END

CAPACITY OF DIFFERENT MACHINES (UHLANDS).

	Speed of cut, feet per minute.					Feed in inches, per revolution.		Depth of cut, inches.			
	Chilled castings.	Tool steel.	Cast iron.	Wrought iron or mild steel.	Bronze or copper.	Roughing.	Finishing.	Steel.	Cast iron.	Wrought iron.	Bronze.
Planers $\left\{ \begin{array}{l} \text{Small} \\ \text{Medium} \\ \text{Large} \end{array} \right.$	—	—	40	—	—	0.03	0.25	0.158 to 0.32	0.39 to 0.79	0.275 to 0.47	0.118 to 0.158
	—	—	40	—	—	0.0625					
	—	—	30	—	—						
Lathes.	5.9 to 9.85	16	30	40	60	about 0.06	0.2	—	—	—	—
Drilling machines.	1.375 to 2.76	Crucible steel, 14	18	25	Bronze, 40	0.003 to 0.01		—	—	—	—
Boring machines.	1.18 to 2.36	14	20	28	40	0.008 to 0.04	up to 0.187	—	—	—	—
Milling machines.	—	25	25	35	50	0.004 to 0.077		—	—	—	—

POWER TO DRIVE (A), WEIGHT (B), AND PRICE (C) OF DIFFERENT MACHINES.

	Planers of medium length.				Lathes.				Radial drillers.			Milling Machines.		
	Width in inches.	A H.P.	B Tons.	C £	Centres in inches.	A	B	C	A	B	C	A	B	C
Small . . .	20 to 28	2 to 4	2.5 to 4	70 to 200	Up to 8	0.75 to 1.25	0.6 to 1.8	25 to 50	0.1 to 0.2	1.6 to 3.75	15 to 75	0.5 to 0.75	0.4 to 1.7 and more	30 to 175 and more
Medium . . .	31 to 48	5 to 8	6.5 to 11.5	200 to 350	8 to 12	1.25 to 3	1.8 to 4	50 to 100	0.2 to 1	3.75 to 6.25	75 to 125	0.75 to 1.5		
Large . . .	48 to 63	8 to 10	11.5 to 22 and more	350 to 600 and more	12 to 24	3 to 8	4 to 17	100 to 500	1 to 2.5	6.25 to 12	125 to 250 and more	1.5 to 5		

CHAPTER VII

MEASURING AND MARKING-OFF

MACHINE work of the best class demands that the accuracy of the work shall be tested by the most refined methods. The high class work of to-day has not always been possible, but has only been attained by many years' practice. The wants of the engineer in regard to accuracy gives rise to the construction of refined measuring instruments; but if the machines are incapable of doing the work as accurately as required, such instruments will be useless. Thus the development in measuring methods has advanced with the development in workshop machinery, steadily advancing to the position in which it is to-day. The limit is determined by two things, the furrows made by the tool (as previously noted), and the cost of machining. In order to keep the cost of accuracy as low as possible, the aim has been, throughout the whole development, to combine accuracy with high speed work. During the last few years the progress in this direction has been remarkable.

Degrees of Accuracy.—The accuracy of measurement depends, firstly, upon the class of work. An architect would give sizes in feet and inches, as differences of quarters or tenths of inches would be of little importance in building work. A cabinet maker might work to quantities as small as quarters or eighths of an inch, as greater accuracy would only be waste of

time. There may be times, however, as the fitting of a small door, when greater accuracy is required; but generally speaking we may say that he works to an eighth of an inch.

The engineer, on the other hand, has to do work of quite another class, and one which to-day stands alone in the accuracy of measurement. It is not uncommon in machine work to measure thousandths of an inch, an error of two or three thousandths being the limit.

If two pieces, such as journal and bearing, are to fit together, they may be machined to fit together by trial. It does not matter if the journal be a tenth of an inch too large, as the bearing may be bored out to fit; but in this case it is necessary to have them marked to show that they belong to each other.

This process is always possible in the workshop, but it will be readily seen that it causes great loss of time. To avoid this we must have some method by which the bearings and journals can be machined to fit, and yet be interchangeable. By means of such a method we could take any bearing from a lot of such, and fit it on any journal from a corresponding lot, the whole, of course, being machined to the same size. The saving of time by such a method is apparent.

Measuring.—Let us consider the process of machining, say, a shaft for a bearing. The turner receives the bearing, which has been bored by another turner, and measures the diameter with his “insides,” or inside calipers. For more accurate measurement he may use the inside micrometer gauge, with which the size may be taken to a thousandth of an inch. He turns the shaft till, by using the gauge or calipers, it is a small amount larger than the required size, and then tries it in the bearing. After this he turns off the

requisite amount by trial, getting the correct fit by feeling the tightness between the shaft and bearing. Thus he measures to hundredths and "feels" thousandths — a more reliable test than measurement.

Plug and Ring Gauges.—As the smaller differences can be more readily "felt" than measured, it is only rational to assume that engineers have adopted some method to make use of it. This is done by means of the plug and ring gauges, consisting of spindles or plugs, on each of which fits a collar or ring. They are made of hardened steel, and are accurately ground to standard sizes by the use of micrometer screws and particular measuring machines. They are so accurate that they will only fit together when greased, the error being less than one thousandth of an inch. Further, the warmth of the hand is sufficient to prevent them fitting together, and care should be taken that they are kept cool. After years of use, in spite of the best hardening, the surfaces wear away, and they require to be renewed.

By means of these gauges it is possible to machine shafts and bearings accurately, so that they are all interchangeable. A row of 2-inch shafts are so machined that the ring passes over each without being slack, while the plug will fit in all the corresponding bearings. Accurate work is done without the workman troubling himself about thousandths of an inch.

End Gauges.—If the plug and ring gauges be employed for large diameters, say, cylinders of 8 or 9 feet, it will be seen that in addition to being uneconomical they become a nuisance. To overcome this difficulty end gauges are used. They consist of

steel bars having their ends shaped to the spherical surface, of which their lengths are the diameters. The advantage gained by the use of spherical and measuring rods is easily seen when we compare the use of them with the use of ordinary staffs or gauges. If we wish to measure the bore of a large cylinder and use the ordinary staff, the size will only be correct provided the staff be inserted perpendicularly to the axis of the cylinder ; any obliquity leads to inaccuracy. If, however, we use spherical end measuring rods this disadvantage is removed, because, as the ends are parts of a large sphere, the distance between the points of contact of the ends and the bore of the cylinder is the same, whether the rod is slightly oblique or not.

Caliper Gauges.—The great disadvantage of the plug and ring gauges is the inability of determining whether the work is truly circular ; they merely tell us that the things will fit together. If, in addition to fitting together, the shaft and bearing are to be truly circular, a thin slice of both plug and ring are necessary, when, by turning these round the diameter, any depression in the surface may be detected. Such slices are known as caliper gauges and are used for the best class of work. Each gauge is made of a particular weight, so that the turned shaft has the correct diameter, when the gauge just slips over under its own weight. This is a very good system, and eliminates any personal error.

What are the advantages and disadvantages of these measuring instruments ? The great disadvantage of the use of calipers and straight edge, is that the measurement depends upon the eye, and therefore is not capable of great accuracy. On the other hand it is quickest, but only to be used for the roughest class of work, where good “ fits ” are not important. The

micrometer caliper and inside gauge are capable of good work, but the efficiency depends entirely upon the workman. An expert machinist will test his gauge to see that it is always accurate, and will use it in such a way that the best results are obtained. An inexperienced man will not bother about testing, and it will be a matter of chance when the work he turns out is equally good.

The use of plug and ring gauges has two disadvantages. Firstly, every man has his own idea about the fitting of the plug into a bored hole, thus the differences that exist between a number of holes are not considered equal by different men. The workman may consider the "fit" good, while the foreman considers it bad enough to be thrown away. The consequence of this is continual trouble, all due to the differences in personal "feel."

The second disadvantage depends completely upon the first. The machinist, in order to prevent wasters, works, perhaps, too carefully, producing work which is more accurate than desired. Consequently the time and power expended on the work is excessive, and the return upon the capital outlay insufficient. This is a serious difficulty which cannot altogether be avoided by the use of plug and ring gauges, but, fortunately, there is a means of overcoming it.

Limit Gauges.—With the system of limit gauges, only recently introduced, the difference or inaccuracy due to the personal "feel," is entirely eliminated. Such a system was necessary, not only on account of the faults of the plug and ring, but also to take advantage of the high class machinery and high speed of working. A plug limit gauge consists of a double-ended plug having one end, one or two thousandths of an

inch larger than the desired size, the other end being the same amount smaller, the rings being made in the same way. The difference between the ends and the actual size will depend upon the accuracy desired. When used for the boring of a hole, the small end or "good side" must fit in, while the large end or "waster side" does not go in. The gauges must not be forced and twisted, but must go in easily, and when these points are attended to the work will be as accurate as the gauges are designed to make it.

Each workshop will determine the amount of "play" or "clearance" necessary, and make the gauges according to their experience of these quantities. The ambiguous terms, "easy fit," "good fit," and "tight fit," will disappear to give place to the more accurate definitions of the limit gauge system.

The differences between the sizes of the ends will not always be the same in the one workshop; but will be smaller for small sizes, and increase gradually with the diameters. These quantities can be readily seen by the young man, as the gauges have the sizes stamped on the ends as well as the words, "to go in" at one end, and "not to go in" at the other.

The introduction of the limit gauge system was one of the greatest advances in workshop practice; it, very happily, took the place of the "good old custom," which was so difficult and costly.

Screw Gauges.—In addition to the gauges for circular bodies, there are others, known as screw gauges, for screws and nuts. The plug is a double-ended gauge, having at one end a plain cylindrical part that just fits in the hole to be tapped, and at the other a screwed end which should just screw into the nut when finished.

They are not to be confused with the thread gauges, thin strips with teeth, resembling a portion of saw blade, which are used only to measure the number of threads per inch. The former not only measures the threads per inch but also the diameter and general condition of the screw.

Tool Room.—The correct use of all the refined measuring instruments and systems will enable the young man to quickly become familiar with the processes dependent upon them; things which cannot be dealt with here. He is, however, recommended to spend some time in the tool room, where the refined methods are mostly used, and pay particular attention to the testing and renewing of gauges, templates, etc. This is most important for the man who will have to spend time later in the workshop, as he will then be able to speak with authority about good and bad work and their causes.

Marking Off.—This is an important process in the workshop, and one worthy of particular notice, especially when the young man is about to do the work himself. The importance has already been referred to in a previous chapter.

The position of the marker-off depends not only upon the marking off of castings and forgings simply, but also upon the advantageous division of the work. He does his work in such a way that inexperienced men working on the castings he has marked off shall not make blunders. Thus it will be readily seen that the marker-off must be an expert, both in measuring and the reading of drawings. The average workman merely follows the "centre-dots" of the marker-off, and does not refer to the drawings and blue prints which are more or less unintelligible to him. The number of

Observation Hints.

Note the following tools and appliances :—

Depth gauge,	V blocks,	Micrometer calipers,
Parallel blocks,	Plum-bob,	Feelers,
Marking-off plate,	Protractor,	Thread gauge,
Surface gauge,	Micrometer inside gauge,	Wire gauge,
Spirit level,	Dividers,	
Square,	Scribing block,	Centre punch.
	Scriber,	

CHAPTER VIII

FITTING, ERECTING, AND TESTING

Value of Handwork.—The work in the fitting and erecting shops is not only intended to acquire expertness in handwork, but also to acquire a knowledge of the value of handwork. A thing that must never be forgotten is that hand labour is much more costly than machine work, and the young man must endeavour to learn when its use is justifiable. Of course the fitter and erector cannot be entirely eliminated; there will always be work for them to do; but it should be cut down to the absolute minimum. It should be noticed how the erecting shop depends upon the fitting as well as the machine shop, and that it has not always the same importance in all works. He must learn these things by keeping his eyes open, and as a guide to him a few words may be said about one or two things.

The ratchet brace is a very useful tool when holes are to be drilled by hand; but when the young man has fatigued himself for two or three days in this way he will be in a much better position to estimate the expense in time and trouble, than if he had taken the statement from the book. He can appreciate the economy effected when the holes are so arranged that they may be drilled in the machine. Being thus familiar with the difficulties due to the designer's inattention to detail, he is not likely to err in the same direction. He will know that it is better to have the work take half an hour longer in the machine shop and

fit well, than pay the fitter a higher rate of wages to do the same work in a longer time.

Another thing of importance is the prevention of errors and bad workmanship in the erecting shop. This can only be done by careful supervision of the work as it progresses, and by applying accurate tests. The work is to be tested by templates and the like during erection, and on completion the machine or engine is to be tested under working conditions. The reasons and methods used for such work are to be particularly noted, a matter of hard work for the young man, but of the greatest importance.

The experience gained from the constructive work in the erecting shop has many applications, chiefly in regard to the contact of pieces which fit together. As an example, a crankshaft supported in more than two bearings may be taken, in the design of which it may be assumed that it rests equally in each. Now, every experienced fitter knows that it may not do so. The good designer also knows this, and takes account of the changes when making his design. On the other hand, the purely theoretical designer does not know of such variations, and wonders why his shaft is too weak. This aspect of the work in the erecting shop cannot be considered until the young man has already spent some time there. It will be found more profitable, at the first, to devote attention to the objects aimed at by the various mechanical processes, and the degree of success attained. To this end a few things, likely to be overlooked, are noted in the following:—

Rigid Fastenings.

Cold Riveting.—Of the various simple processes met with in the fitting and erecting shops, the connecting

of parts together is one of the most common and most important. The process of hot riveting has been previously described; but riveting is also done cold, such cold riveting being chiefly done in the fitting shop. The process is not to be understood merely as the insertion of a cold rivet which is afterwards riveted over, but also as the riveting or "burring" of the ends of screws, pins, and the like, when the nut or similar thing (on the screw or pin) is not to fall off if it should happen to work loose. Such cold riveting is only to be of small amount, and when necessary, care must be taken that there is sufficient metal for the work. In the case of bolts, which are often treated in this way, two or three taps with the ball pane of the hand hammer are sufficient to absolutely prevent the accidental removal of the nut. In other cases, the edges of the hole may have to be "countersunk" to accommodate the metal which is knocked over. Such things are to be studied and understood, so that they may be correctly represented on the drawing.

Shrinking On.—Shrinking on consists in heating the part which contains the hole so that its diameter is larger, when it is put upon the shaft, and then cooling. If the hole were bored out slightly smaller than the shaft upon which it has to fit, the shrinking would make it bind tightly upon it. The process is used to shrink crank webs upon crank shafts, and the well-known example of shrinking wheel tires upon cart wheels. It is, however, being superseded in many cases by pressing.

Shrinking on depends greatly upon the temperature and the care taken in boring out the hole to the correct size; and for this reason it is only to be done by experienced men.

Soldering.—Another fixed fastening, well known and, in certain cases, often applied, is soldering. It may seem that as this is more of a tinsmith's business than an engineer's, that it is of no consequence; but this is not so, and a knowledge of the soldering processes will always be found of use. There are small oil pipes, water pipes, and the flanges of copper pipes to be soldered, and the designer who is not familiar with the processes of soldering is likely to have a deal of worry over many details. It will therefore be advantageous to visit the coppersmith's shop occasionally to watch the bending of copper pipes and the brazing of the flanges; also to attend when bearings are being run with white metal.

Solders.—In choosing a solder for any particular work we are guided chiefly by the melting point, strength, and colour. There are, of course, different kinds, corresponding to different ingredients, the engineer preferring one that is proportionally close grained and hard, and which resists pressure fairly well. Such an alloy known as brazing metal or hard solder is invariably used. It consists chiefly of granulated brass and zinc, to which a small amount of tin may be added, and melts at a temperature of about 300°C . (573°F .). The higher the percentage of brass (up to 85 per cent.) the more thickly fluid it is, and great care must be taken to see that it enters the seam to be brazed. For less important work, such as the jointing of plates which do not require great strength, soft solder or tinman's solder is used. It consists of an alloy of tin and lead in different proportions, and, melting at some point between 180° and 250°C . (356° and 482°F .), is more easily used than hard solder.

The melting point of the solder must, obviously, be less than that of the metals joined, or the surfaces will be destroyed. Then, as in welding, a good clean surface is necessary, and this is prepared either by filing or by etching with an acid. To make the solder run into the metal surfaces, a flux is used as in the blast furnace process. For soft soldering, zinc chloride, made by mixing zinc (metallic) with hydrochloric acid, is used; while for hard soldering various brazing powders are used. The flux also tends to reduce any oxidation which may take place in the fire when the surfaces are heated, and therefore must be capable of covering the metal without dropping off. For soft solder there are colophonium and sal ammoniac; for brazing, borax; for more thickly fluid solder, glass powder. It must be remembered that the vapour given off during the process is injurious to the health.

Any work which has been soldered must not be relied upon for the transmission of force, this remark also applying to cold riveting. It makes a tight joint suitable for all kinds of fluids, but is greatly dependent upon the care of the man who does the work; this being the greatest disadvantage of the process.

Pressing.—Between the permanent or fixed fastening and the removable or temporary fastening there is the connection by pressing. This is somewhat similar to the process of shrinking on, except that the contraction of the hole is caused by hydraulic pressure from the outside instead of by change of temperature. It has increased in favour during the last few years, owing, chiefly, to the improvements in hydraulic presses. Any degree of uncertainty may be removed by the use of cotters or by cold riveting.

Removable or Temporary Fastenings.

Screws.—Screws come first in this class of fastening, and they must be particularly studied. A complete knowledge of the different kinds of threads (V, buttress, square, knuckle, Whitworth, gas and British Association), as well as the shapes of bolt heads and nuts (square, hexagon, circular, countersunk, snap, castle nuts and flange nuts), must be acquired in the workshop. It is good for the young man to learn from his own experience the differences between bolts, studs, and fitted bolts, and the particular uses of each.

Lastly, he is directed to note the different methods of making screws secure, and their applications. Even such a common thing as a spanner is of importance, as the novice tends to put the pressure at the wrong place and “screws up” too tightly. When this happens, it will be seen that the bolt is weakened, because a load is put upon it before the useful load comes on.

Keys.—The second principal method of removable connection is the use of keys. They are used chiefly for the connection between shafts and wheels, and are of different forms. Notice well the manufacture of the key, keyway, the fitting of the key, and the taking down of the work—the most important things in regard to this connection.

Jointing or Packing.—Jointing is immediately related to the method of connection, being the material used to prevent the escape of liquids and gases under pressure. There are two kinds of packing, one for a joint which has no motion of the parts (pipe joints), and the other for joints which have relative motion of the parts (piston rod and stuffing box). The

packing for the stuffing box of a steam engine is of great importance to the engineer; he must be able to estimate correctly the accessibility, resistance to heat, and the general efficiency. The materials chiefly used for packings are asbestos in sheets and cords, indiarubber made into sheets and cords along with canvas, leather, hemp; and for joints subjected to high temperature and relative motion the metals copper, brass, and lead. The young man will not probably meet with all forms of packing in the shop in which he works; this is, however, of no consequence, as the principles underlying the choice of packings are practically the same for all.

Grinding-in.—Another method of making a joint is known as “grinding-in,” in which no packing is used. It is always met in engine building in the case of valves, and is of great importance. The young man is recommended to note particularly the circumstances in which such joints are employed, how they are made, and how the pressure is used to keep them tight.

Another form of packing rendered necessary by the use of the steam turbine is known as “labyrinth” packing. Its construction is to be noticed when possible, but the explanation of it must be left to a later time, as it depends upon theoretical principles.

Scraping.—A process related to packing is the fitting of one surface on another by means of scraping. It is a tedious process, can only be done by experienced men, and depends for good results upon the rigidity of the metal. On account of the great expenditure of time required, it is exceedingly important to exclude it entirely when possible.

There are many other processes and things in the fitting and erecting shops which might be referred to.

But the mention here is not nearly as good as a view of the actual things, as the young man cannot then read over the subject mechanically. In the observation hints at the end of the chapter further subjects of importance are mentioned.

Testing.—An important branch of work connected with erection is the testing of the finished engine or machine. By this is understood the testing of the engine under working conditions and for a specified length of time. Such testing is necessary as a safeguard to both the buyer and the seller, as it minimises the risk of accident due to bad material and design; reduces any loss of efficiency due to bad workmanship; and prevents any question of liability on account of faults due to careless use after delivery.

During the test the input and output of the engine are noted by means of various instruments and appliances, and from these observations the "results of the test" are deduced. There are many things to be found in the testing shop, but they differ for different work. Generally speaking, it may be said that in addition to the measuring instruments there must be sufficient "gear" to enable the engine to run under working conditions. In the case of the steam engine, for example, there must be a supply of steam, means to deal with the steam when it leaves the engine, and suitable foundations.

The work in the testing shop is a fitting conclusion to the practical training, as it enables the young man to appreciate and use much of the knowledge gained in the other shops. Such work must never be neglected, and when engaged in it he must take as many notes as he can, and (if he cannot work out the results himself) get the results when worked out.

Observation Hints.

How does the fitter know when a valve and its seating are ground in?

What are steady pins? When are they used, and how withdrawn?

How are studs driven and withdrawn?

What is the object of starting screws as used in cylinder covers?

When erection is commenced, where is the main shaft laid?

How are piston rings fitted?

How is a piston put into a cylinder?

How are eccentric sheaves set and keyed in position?

How are slide valves set?

To what extent can portable machines be used for the machining of heavy castings when they are driven from the line of shafting?

How is an engine governor erected and adjusted?

How are oil-grooves made in iron, bronze, and white metal?

Note the following tools and appliances:—

Centre punch,	Box spanner,	Hand-vice,
Shifting spanner,	Vice clamps,	Round-nose,
Tube vice,	Cross-cut,	Hand-saw,
Flat chisel,	Stocks and dies,	Square file,
Snips or shears,	Half-round file,	Scraper,
Round file,	Reamer,	Copper bit,
Saw file,	Countersink,	Circular spirit
Fluted reamer,	Spirit level.	level.
Plum bob,	Screw-driver,	
Pin punch,	Pipe cutters,	

APPENDIX

THE INSTITUTION OF CIVIL ENGINEERS.

A REPORT ADOPTED BY THE COUNCIL, 24TH APRIL, 1906.*

EDUCATION AND TRAINING OF ENGINEERS.

Report of a Committee appointed by the Council of The Institution of Civil Engineers on the 24th of November, 1903.

Members of the Committee:

SIR WILLIAM H. WHITE, K.C.B., D.Sc., LL.D., F.R.S., <i>Chairman.</i>	
ARCHIBALD BARR, D.Sc.	HARRY E. JONES.
SIR JOHN WOLFE BARRY, K.C.B.,	SIR ALEXANDER B. W. KENNEDY,
LL.D., F.R.S.	LL.D., F.R.S.
SIR ALEXANDER R. BINNIE.	HENRY LOUIS, M.A.
ALEXANDER GRACIE.	A. T. TANNETT-WALKER.
ROBERT KAYE GRAY.	R. L. WRIGHTON, M.A.
J. HARTLEY WICKSTEED.	

WE have the honour to submit the following Report and Recommendations for the consideration of the Council of the Institution of Civil Engineers, in accordance with the terms of reference to this Committee, which was appointed—

“To consider and report . . . as to the best methods of training for all classes of engineers, including both scholastic and subsequent technical

* Reproduced by permission of the Council of the Institution of Civil Engineers.

education ; it being an instruction to this Committee that the principle shall be maintained that the education of an Engineer must include both practical experience and scientific training."

It is desirable to place on record, at the outset, a brief account of the circumstances under which the Committee was appointed, by unanimous resolution of the Council, on the 24th November, 1903.

In taking this action the Council of the Institution of Civil Engineers proceeded on lines which had been followed for a long period, with a view to improvement in the training and status of civil engineers.

An exhaustive inquiry had been made in 1868 into then existing conditions and systems of engineering education in the United Kingdom and in foreign countries ; and the results of this inquiry were published by the Institution in 1870. In 1891 another statement was published dealing fully with the facilities for engineering education afforded at that date by the engineering schools of Universities and Colleges in the British Dominions.

The educational qualifications required of candidates for admission as students in 1889, and subsequently the system of examinations established in 1897 for students and associate members of the Institution of Civil Engineers, furnished further proof of the importance attached by the Council to the higher education of civil engineers.

During the year 1903 renewed discussions on this subject took place at the Engineering Conference of the Institution of Civil Engineers, and at meetings of the Institution of Mechanical Engineers, the Institution of Naval Architects, and important engineering

societies outside London. These discussions showed wide differences of opinion as to the best methods of training engineers, but indicated a general feeling in favour of thorough investigation of the subject by some body representing all branches of engineering, whose conclusions would command the attention of all who were interested in the education and training of engineers. This general desire was definitely expressed in a letter of 8th May, (1903) addressed by the President of the Institution of Mechanical Engineers to the President of the Institution of Civil Engineers, stating that the Council of the former society considered it desirable that a representative committee should be appointed by the Council of the Institution of Civil Engineers to consider and report on the whole subject of engineering education. This suggestion was the immediate cause of action by the Council of the Institution of Civil Engineers (November, 1903) after the summer vacation, when steps were taken to appoint the Committee whose work is now completed.

The Council then decided to request the engineering societies named below to assist the proposed inquiry by nominating representatives to serve thereon :—

The Institution of Mechanical Engineers.

The Institution of Naval Architects.

The Iron and Steel Institute.

The Institution of Electrical Engineers.

The Institution of Gas Engineers.

The Institution of Engineers and Shipbuilders in Scotland.

The Institution of Mining Engineers.

The North-East Coast Institution of Engineers and Shipbuilders.

All these institutions complied with the request, and nominated representatives, and the constitution of the Committee was completed in February, 1904, as under:—

Sir WILLIAM H. WHITE, K.C.B., D.Sc., LL.D., F.R.S.,
Past-President Inst. C.E., *Chairman*.

The PRESIDENT of the Institution of Civil Engineers (*ex officio*).

Sir JOHN WOLFE BARRY, K.C.B.,
LL.D., F.R.S., Past-President
Inst. C.E.

Sir ALEXANDER B. W. KENNEDY,
LL.D., F.R.S., Vice-President
Inst. C.E.

J. HARTLEY WICKSTEED, M. Inst.
C.E. (*representing the Institution
of Mechanical Engineers*).

ALEXANDER GRACIE, M. Inst. C.E.
(*representing the Institution of
Naval Architects*).

Sir EDWARD H. CARBUTT, Bart.,*
M. Inst. C.E. (*representing the
Iron and Steel Institute*).

R. KAYE GRAY, M. Inst. C.E.
(*representing the Institution of
Electrical Engineers*).

HARRY E. JONES, M. Inst. C.E.
(*representing the Institution of
Gas Engineers*).

Prof. ARCHIBALD BARR, D.Sc.,
M. Inst. C.E. (*representing the
Institution of Engineers and Ship-
builders in Scotland*).

Prof. HENRY LOUIS, M.A. (*repre-
senting the Institution of Mining
Engineers*).

Prof. R. L. WEIGHTON, M.A.
(*representing the North-East Coast
Institution of Engineers and Ship-
builders*).

J. H. T. TUDSBERY, D.Sc., M. Inst. C.E., *Secretary*.

J. G. HENDERSON, B.Sc., Assoc. M. Inst. C.E., *Assistant-Secretary*.

As the members of the Committee were busily occupied and widely scattered over the country, it was felt from the first that much of the work must be done by correspondence, and that it would be advantageous before meetings took place to settle the heads under which the inquiry might be arranged most conveniently. For that purpose the following memorandum

* On the regretted death of Sir Edward Carbutt, in October, 1905, Mr. A. T. Tannett-Walker, M. Inst. C.E., was appointed to serve on the Committee as a representative of the Iron and Steel Institute.

was prepared and circulated by the Chairman to the members of the Committee.

PROPOSED SECTIONS OF INQUIRY.

1. *Preparatory Education in Secondary Schools* ; with special reference to suitable training of youths, who are intended for the engineering profession, in mathematics, elementary science, modern languages and handicrafts.
2. *Training in Offices, Workshops, Factories, or on Works* ; including the decision as to the period or periods at which such training can best be given, its character and duration. The possibility to be considered of giving to the preliminary stages of this practical training as broad a character as possible, so as to prepare students for any branch of engineering they may subsequently enter.
3. *Training in Universities and Higher Technical Institutions.*

Opinions to be formed as to :—

- (a) The most suitable age at which average students could begin this course.
- (b) The possibility of arranging the earlier courses of study so as to be common to all branches of engineering.
- (c) The duration of such common courses of study.
- (d) The extent to which specialisation should be provided for in technical institutions, and the extent to which it should be carried.

4. *Post-graduate Work.* How it can best be organised and maintained :—

- (a) At Universities and higher technical institutions.
- (b) On actual works, and in mines, factories, etc.

At the first meeting of the Committee (held on the 24th February, 1904) this memorandum was approved, and it was decided to entrust detailed consideration of the first section (Preparatory Education in Secondary Schools) to a Sub-Committee consisting of Sir Alexander Kennedy (Chairman), Professors Archibald Barr, Henry Louis, and R. L. Weighton, and Mr. Alexander Gracie. It was further agreed that the Committee, as a whole, should undertake the consideration of (a) Practical training in offices, workshops, factories, or on works; and (b) Training in universities and higher technical institutions.

In prosecuting their inquiries the Committee thought it essential to obtain, either orally or in writing, the opinions of persons having experience in engineering education, and of eminent engineers practising in various branches of the profession. It was desired to make this record of opinion precise, representative, and comprehensive; for which purpose members of the Committee undertook to suggest the form in which inquiries should be framed, to give the names of those to whom application might be made, and to indicate general detailed action, which, in their judgment, would be of value in the collection of opinions and information. These suggestions were summarised and condensed, under the supervision of the chairman, by the secretary and assistant-secretary. The

schedules of questions approved by the Committee and subsequently issued were prepared on this basis.

These preliminaries necessarily occupied a considerable time and entailed a large amount of correspondence. Their final result has been the attainment of both definiteness and wide range in the questions circulated ; and has secured the collection of a great body of opinion from representative engineers in active practice, professors and teachers in technical colleges and universities, and others whose advice has been of value in reaching a decision on matters referred to the Committee. The scope of their inquiry was necessarily extensive, and the Committee desire to express their gratitude to the large number of gentlemen who have favoured them with advice and opinions. They recognise that those who have given assistance are actively engaged in educational and professional work, which made it no easy matter to devote attention to the questions asked. On the other hand, the numerous and full responses made by men whose experience gives authority to their opinions and recommendations, have enabled the Committee to proceed with greater certainty in framing their Report. Diversities of opinion have been disclosed in regard to some details, as was inevitable from the nature of the subjects ; but in all main features of their recommendations the Committee have support from the large majority of their professional colleagues and of the teachers in universities and higher technical institutions. This fact cannot fail to carry great weight with those for whose benefit the Report has been prepared.

The Committee are of opinion that it would not have been possible in any other way to have secured equally full consideration of the subject, or so valuable a mass

of information and opinion in regard to the principles it is desirable to follow in training engineers. More time and labour have been involved by adopting the method of written communication instead of oral evidence; but a much larger number of men has been reached, and the final result is more satisfactory.

I. INQUIRY AS TO PREPARATORY EDUCATION.

(See Appendix I.)

The details of this portion of their work were entrusted by the Committee to the above-mentioned sub-committee. A schedule of the questions issued by the sub-committee will be found in Appendix I., which also contains an analysed summary of the replies. This schedule was issued to 120 representatives of the following classes :—

- (1) Teachers in engineering colleges.
- (2) Headmasters of secondary schools at which it is believed special attention is paid to scientific training.
- (3) Engineers not engaged in teaching.

Replies were received from 80 per cent. of the gentlemen whose opinions were invited; and from these replies definite conclusions were deduced as to the prevalent opinions on points raised by the questions.

The Report which the sub-committee submitted to the main Committee was considered at a meeting held on the 23rd March, 1905, and was then approved and adopted.

The following are accordingly the recommendations of the Committee in respect of the most suitable

preparatory education for boys who are intended to become engineers.

Recommendations in Respect of Preparatory Education.

1. It is desirable that a boy intended for the engineering profession should, before leaving school and commencing to specialise, have attained a standard of education equivalent to that required by the Institution Studentship Examinations; and that he should not commence his special training until he is about seventeen years of age.

2. A leaving examination for secondary schools, similar in character to those already existing in Scotland and in Wales, is desirable throughout the United Kingdom. It is desirable to have a standard such that it could be accepted by the Institution as equivalent to the studentship examination, and by the universities and colleges as equivalent to a matriculation examination.

3. Advanced teaching of history and geography, with instruction and practice in essay-writing and in précis-writing, should be included in the ordinary school curriculum; and the instruction in English subjects should include at least an introduction to English literature.

4. Greek should not be required, but an elementary knowledge of Latin is desirable. The study of Latin should, however, be discontinued during the last two years of attendance at school, or after the standard required for the leaving-certificate has been attained. Modern languages, especially French and German, should be studied, and should be taught colloquially, or

in such a way as to give the pupils a practical knowledge of each language, sufficient to enable them to study its literature and to converse in it with some degree of facility.

5. Instruction in mathematics should be given by methods differing considerably from those usually adopted in the teaching of this subject merely as an intellectual exercise. The geometrical side of mathematics should be fostered, and before they leave school boys should be conversant with the use of logarithms, and with at least the elements of trigonometry, including the solution of triangles. It is also of importance that instruction in practical arithmetic should be carried further than has been generally the case hitherto, with the object especially of encouraging the use of contracted methods and operations in mental arithmetic; and of encouraging also the expression of results with only such a degree of (numerical) precision as is consistent with the known degree of certainty of the data on which they are or may be supposed to be based.

6. It is preferable that boys should attain at school a general knowledge of elementary physics and chemistry, or of what is sometimes called "Natural Philosophy," rather than that they should pursue in detail some particular department of science.

7. Special attention should be given to drawing; the instruction should include ordinary geometrical drawing with orthographic projection, curve-drawing, freehand drawing, and practical mensuration.

8. Work in the nature of handicraft, such as carpentry or turning, or elementary field-surveying, may be encouraged as a recreation, but should not be required as a school exercise.

9. It appears to be impossible in the general

curriculum of school work, to include advantageously time for instruction in such a subject as surveying, which has been suggested.

The Committee recommend that this scheme of preparatory education should be officially communicated to the Board of Education and widely circulated amongst those engaged in the conduct of secondary schools and engineering colleges, in order that future schemes of tuition of youths who contemplate entry into the engineering profession may be guided thereby. The Committee are of opinion that if this course is taken it would assist in overcoming one great difficulty now universally felt in institutions in which applied science is taught. At present a considerable proportion of students enter technical institutions ill-prepared, and at least one year has to be devoted to instruction which ought to be secured beforehand. Proper preparation is essential if students are to derive full benefit from special instruction in applied science. Professors and teachers ought not to be required to undertake subjects that should be taught elsewhere, but should be left free to devote themselves to scientific and technical instruction, which is their real work.

II. INQUIRY AS TO ENGINEERING TRAINING. (*See Appendix II.*)

The Committee found it convenient to deal with Sections 2, 3, and 4 of the inquiry together. These include training in offices, workshops, factories or on works, generally designated "practical" training; training in universities and higher technical institutions; and post-graduate work. In these instances also, as explained above, a schedule of questions was

framed (Appendix II.) and was circulated widely ; but the Committee embodied in the schedule their conclusions on certain important subjects which had been thoroughly discussed by the members, and on which they were unanimous. In that course there was no interference of the free expression, by those whose opinions were solicited, of views contrary to those of the Committee ; and the replies indicated clearly that this fact was realised. Nor were the comments of correspondents limited to points raised in the schedule. On the contrary, perfectly independent statements of opinion were submitted in many cases. The Committee desired primarily to ascertain the views of men whose opinions were entitled to respectful consideration, in consequence of their experience and study of education and of engineering training. In all instances these communications have received due consideration by the Committee, after being carefully grouped and analysed.

Each member of the Committee was at liberty to forward the names of gentlemen to whom schedules should be sent, and each institution was asked officially to suggest names, in order that the list might be made as complete as possible, and that each department of engineering might be adequately represented. The total number of schedules issued was 676, and the total number of replies received was 267. Their distribution over different branches of the profession may be classified roughly as in table opposite.*

The gentlemen whose opinions were asked were actively engaged in professional work, and in consequence there were delays in making replies. Repeated applications were necessary before the inquiry could

* P, 185,

be completed, and it was decided finally to make the 1st November, 1905, the latest date for the receipt of replies.

An analysis of the replies is given in Appendix II. From this it will be seen that the tentative suggestions and recommendations embodied by the Committee in their schedule have received very general support; this support has been given by each of the great sections of the engineering profession. A few correspondents expressed radically different views; but, in

	No. of Schedules issued.	No. of Replies received.
1. Engineers engaged in constructional work (railways, docks, harbours, canals, water- works, sewerage, etc.) }	34	16
2. Mechanical engineers	200	82
3. Mining engineers	72	22
4. Iron and steel manufacturers	47	16
5. Naval architects, shipbuilders, and marine engineers }	119	32
6. Gas engineers	94	39
7. Electrical engineers	66	30
8. Professors, and others who are, or have been, engaged in teaching }	44	30
	676	267

the main, the opinions of the Committee have been endorsed, and this result is satisfactory, since it indicates the possibility of practical effect being given to the recommendations. The Committee were not assisted so fully by replies to their question on mathematical teaching as to others; they therefore obtained specially the opinions of their colleagues engaged in tuition, and of other gentlemen who have large experience in this matter.

The Committee have had in view throughout what may be termed an "average boy," of ordinary ability, whose parents are in a position to secure for him a thorough training before he begins his actual professional work as an engineer. They recognise the necessity that will always exist for providing also suitable means of training for young men not so favourably situated, who work their way by sheer ability and force of character, and whose earlier careers do not permit of the methodic preparatory education and training which they consider best for the average boy. The Committee also recognise the certainty that other most valuable recruits for the engineering profession will continue to enter at a later period of life, and from other systems of education and employment. At the same time, it is obvious that, in all such cases, men may be trusted to find their way, and to avail themselves of existing opportunities for instruction and training. Their concern, therefore has been with the best general scheme adapted to the average boy.

The Committee have not overlooked the established customs of universities and colleges to which engineering schools are attached, and have given weight to the necessity for arranging terms and courses of study with due regard to general efficiency in the conduct of these institutions. Consequently they do not recommend absolute uniformity of arrangement in college courses of study or in their method of association with practical training ; nor do they consider such uniformity necessary. In Scotland, it may be anticipated that the alternation of winter study at the universities with long summer vacations, usually spent in practical work, will be continued ; whereas in England the sessions and vacations will be arranged differently.

Other varieties of practice exist or will be introduced; and, in the judgment of the Committee, considerable latitude is permissible in these matters without loss of educational efficiency.

Recommendations in Respect of Engineering Training.

The Committee desire to preface these recommendations by the statement that they are unanimous in the opinion that engineering training must include several years of practical work, as well as a proper academic training. Long experience has led to general agreement amongst engineers as to the general lines on which practical training should proceed; and it has, therefore been unnecessary to deal at any great length with that matter in the recommendations. It must not be supposed, however, that the fuller treatment of academic training in the following pages indicates its greater relative importance; the reason for this fuller treatment is to be found rather in a desire to suggest courses of study which can be best associated with the practical training that is essential to engineering education.

Taking the schedule of opinions and questions relating to practical training (Appendix II.) as determining the order followed, the Committee make the following recommendations. The numbers refer to the sections of Appendix II.

1. The average boy should leave school when he is about seventeen years of age. Much depends upon the development of individual boys, but the minimum age should be sixteen and the maximum eighteen years.

2. The practical training should be divided into two parts, whenever that arrangement can be made, and the preliminary stage of practical training should consist in all cases of at least a year spent in mechanical engineering workshops. This "introductory workshop course" is desirable even when students do not contemplate devoting themselves at a later stage to what is generally designated "mechanical engineering." Thus, for mining engineers, the machine-shops of a large colliery would be found especially suitable. The Committee are supported in this recommendation by the opinions expressed by a large proportion of the engineers who have been consulted. It is recognised that at present there are practical difficulties in arranging for this workshop year being interposed between the school and college work, and that employers may consider the arrangement objectionable in their interests. On the other hand, the Committee suggest that these difficulties should not be insurmountable; and the general agreement as to its advantageous effect on training leads them to hope that practical trial may be given to the suggestion. In any case, the Committee recommend that an "introductory workshop course" of at least a year should be included whenever possible in the practical training of all engineering students. Where the "introductory workshop course" is possible before the college training, it should not be less than one year, nor more than two years. The longer period may be desirable in the case of boys who are to become mechanical engineers, and useful in all cases when boys leave school at sixteen years. In some cases it may be preferred to take the workshop course after the first year of the college training common to all branches of engineering.

An interruption of college training at a later period must involve great disadvantages.

3. During workshop training boys should keep the regular working hours, should be treated like ordinary apprentices, be subject to discipline and be paid wages.

4. Nothing should be done in the form of evening study which would impose undue strain upon the physique of boys. In some cases this might prevent attendance at evening classes; but experience shows that many boys can attend such classes without physical injury and with great educational advantage. The Committee think it is most important that all boys should at least maintain their scholastic acquirements during the introductory workshop course, and, for the class of boys in question, it is considered that this result might be secured, by private tuition or otherwise, without undue physical strain. Nothing should be done to discourage boys, who so desire and are physically fit, from adding to their knowledge either by private study or by attendance at classes.

5. As a rule it is preferable to proceed to a technical college or university on the completion of the introductory workshop course. This is advantageous to most boys, as it abridges the period between school and college, and lessens the danger of retrogression in knowledge. It also facilitates the arrangement of common courses of study for junior students in technical colleges and universities; and, on the whole, gives the students better opportunities of benefiting by college training.

In some cases—as for example, when boys are intended to become mechanical engineers—it may be advantageous to complete the practical training before

entering college; but if this is done it becomes more important that simultaneous education during practical training should be secured by private tuition or in evening classes; otherwise boys would lose seriously during four or five years' suspension of systematic study, and would be disadvantaged on entering college.

The alternation of college study and practical training is only feasible when (as in the Scotch Universities) the College vacation practically occupies half the year; or in the case of mining engineers, where the official requirements under the Coal Mines Regulation Acts prescribe a minimum period of four months spent in mines before the termination of the college course.

6. For the average student the period of college study should be three sessions, provided he is well prepared before entering college. In the case of students who desire to follow up the science of their profession a fourth year might be added, which would be in some cases post-graduate work, and might come after the practical training is completed. In cases where students are exceptionally well prepared before entering college, or are above the ordinary age, or possibly without the means required for a full course of study, facilities should be given for shortening the course of study.

In all cases the first session might be advantageously devoted to a common course of study by average students, and probably that common course might be extended into the second session without loss to final specialisation.

7. A sound and extensive knowledge of mathematics is necessary in all branches of engineering, although some of these branches require more advanced mathe-

matics in their practice than others. The capacity for acquiring mathematical knowledge varies greatly in individual students, and many who become competent engineers have not the power of acquiring the higher mathematics. These differences of actual requirements and individual capacity must be recognised in courses of instruction, and can hardly be dealt with by any general statement.

It should be possible, however, for the student of average ability who, at his entry upon the study of applied science, has advanced to the stage of preparation in mathematics outlined in the foregoing recommendation as to preparatory training (see page 4) to master sufficiently during the common course of instruction for all engineering students the subjects included under the category of pure mathematics; provided the instruction proceeds in a systematic and well-considered manner.

The Committee endorse the practically universal recommendation, made by those whose special knowledge and experience entitle them to speak with authority, that a sufficient time should be allotted to the study of pure mathematics during the common college-course, to permit the best students to obtain a sound knowledge of Algebra, Trigonometry, Analytical and Practical Plane Geometry, the elements of Solid Geometry, and a working knowledge of the Differential and Integral Calculus, and of the simpler Differential Equations. To this fundamental mathematical training there must be added instruction in Applied Mathematics and Mechanics. The extent to which individual students can be carried in this course must be a matter left to the discretion of the teaching-staff, whose means of observation and power of assessing the capability of

individual students can alone decide the matter. In the judgment of the Committee, it is most important that, when teachers consider that individual students are lacking in the power of proceeding successfully with their higher mathematical studies, time should not be wasted in persevering therewith. On the other hand, many students of this class under proper instruction are capable of benefiting greatly by well-considered courses of instruction in the practical applications of mathematics.

In the later terms of the college course of study, time devoted to purely mathematical instruction should be lessened as compared with the time similarly devoted during the earlier terms; and that given to specialised instruction in engineering subjects should be increased. The most advantageous arrangement, both for students and teachers, will consist in the combination of mathematical and engineering instruction by the professors and teachers of engineering. The teachers of pure mathematics also, in dealing with the students during their common course of study, should be well-informed as to the applications of mathematics in engineering, so that their courses of instruction may be arranged suitably, and that departments of these subjects having no bearing upon engineering may not have given to them unnecessary time or attention.

With regard to the teaching of geometrical drawing, physics, chemistry, and geology, the existing arrangements of the Universities and technical Colleges appear to be satisfactory and to meet all cases.

Without interference with the organisation of individual colleges, it would be found in the highest degree beneficial to arrange conferences between the staffs of all the important teaching institutions; so

that a uniformly high standard of qualification on the part of students, at the completion of their courses of study, may be maintained.

8. At least three to four years should be spent in practical training, inclusive of the "introductory workshop" previously mentioned. The Committee favour a total period of four years' practical training where it can be secured: this being carried out in workshops, on works, in mines and in offices, as may be required in each case. It is highly desirable that a part of this practical training should be obtained in drawing-offices.

9. Where College training is completed before practical training is taken, the total period devoted to the latter should be three years in ordinary cases. Exceptional ability may justify a somewhat shorter period. The hours of work should be the same as if the usual course were followed: the wages paid should be somewhat higher, especially in the later years. The Committee make this general recommendation whilst recognising that this is not the practice in mining.

10. The Committee recommend strongly efficient instruction in Engineering drawing.

Instruction in testing materials and structures, and in the principles underlying metallurgical processes and other practical operations incidental to the branch of engineering in which a student proposes to specialise, should be included in the College course.

In regard to workshop practice in technical colleges, they are of opinion that boys who have spent one or two years in mechanical engineering workshops should not be instructed in workshop practice at technical colleges

11. In connection with the grant of degrees, diplomas, and certificates to engineering students, considerable importance should be attached to laboratory and experimental work performed by individual students, as well as to their progress in mathematical and scientific studies; and degrees, etc., should not be granted on the results of terminal or final examinations alone. Practical unanimity is shown in regard to this procedure by those whose opinions were obtained, and it is considered to be of great importance in assessing the professional attainment of students.

12. Facilities for, and organisation of, post-graduate work by engineering students in Universities and Higher Technical Institutions should be considerably increased. This recommendation is made with the special object of encouraging qualified students to undertake researches which may prove of practical value to engineering operations and processes. The number of such students is not likely to be large at any time, but their influence on younger students should be highly beneficial, and the advantage to engineering and industry should be considerable. In many cases the best period for post-graduate work would be that following the completion of practical training, even when that training follows the College course.

13. The Committee reaffirm the conviction expressed when they issued their inquiry, that the sympathetic assistance of employers is essential to improvement in engineering education and training.

In conclusion, the Committee desire to express their indebtedness to the Secretary (Dr. Tudsbery) and the Assistant-Secretary (Mr. Henderson) for the valuable and unwearied assistance which they have rendered

REPORT ON EDUCATION OF ENGINEERS 195

throughout the inquiry, and would repeat their acknowledgment of indebtedness to all those who have assisted with opinions and information.

W. H. WHITE,

Chairman of the Committee.

J. H. T. TUDSBERY,

Secretary.

7 April, 1906.



APPENDIXES

APPENDIX I.

SCHEDULE OF QUESTIONS RELATING TO PREPARATORY EDUCATION AND TRAINING OF ENGINEERS, ISSUED BY THE SUB-COMMITTEE; WITH A SUMMARY OF THE REPLIES RECEIVED.

QUESTION.	SUMMARY OF REPLIES.
1. What is the proper age for leaving school, having in view the fact that the boy has ahead of him a practical and theoretical training which will cover certainly 4, probably 5, and perhaps 6 years before he can become a regular Assistant in any branch of Engineering work?	Per Cent.
	Average age recommended—
	Less than sixteen . . . 4·5
	Sixteen . . . 19·0
	Between sixteen and seven-
	teen . . . 14·0
	Seventeen . . . 40·0
	Between seventeen and
	eighteen . . . 4·5
	Eighteen . . . 10·0
	Exceeding eighteen . . 8·0
	100·0
2. (a) What is your view as to the desirability of a leaving examination for Secondary Schools? (b) If such an examination is possible or desirable, should it be in the hands of the school itself or of external examiners, or of both conjointly? (c) Could it, and, if so, should it be utilised as the equivalent of a Matriculation or Entrance Examination for the various Colleges giving education to Engineers?	Per Cent.
	(a) Desirable . . . 90·0
	Undesirable . . . 10·0
	100·0
	(b) School itself . . . 5·0
	External Examiners . . 41·0
	Both conjointly . . . 54·0
	100·0
	(c) Yes . . . 93·5
	Doubtful . . . 6·5
	100·0
3. English Subjects. (a) Is it possible to develop further than has generally been the case hitherto, the teaching of History and Geography in what may be called their commercial aspects?	Per Cent.
	(a) Yes . . . 85·5
	Not desirable . . . 14·5
	100·0

QUESTION.	SUMMARY OF REPLIES.
3. English Subjects—continued. (b) Could Précis-Writing be included under this heading? (c) Can anything be done to give extended instruction and exercise in Essay-Writing?	Per Cent. (b) In favour 84·0 Doubtful or not in favour 16·0 100·0 (c) In favour 88·0 Doubtful or not in favour 12·0 100·0
4. Languages. (a) How far is it desirable that boys definitely intended for the Engineering profession should continue the study of the classical languages, or of either of them, until the time when they leave school? (b) If it is thought that the study of these subjects ought to be continued to the end, what amount of time should be spent upon them during the last two years? (c) To what extent can Modern Languages—especially French and German—be taught colloquially or in such fashion as to make them really useful, without the expenditure of unnecessary time on theoretical grammatical exercises or in the study of classical comedies?	Per Cent. (a) In favour 47 Recommend discontinuance at least 2 years earlier . 41 Recommend omission of classics altogether . 12 100 (b) About 5 or 6 hours a week 77 About 10 hours a week . 23 100 The replies to (a) and (b) refer, in the majority of cases to Latin alone, the general opinion being that Greek may be either omitted entirely or discontinued at an earlier stage. Per Cent. (c) Approve of this method . 77 Doubtful or not in favour 23 100 In many cases residence abroad is recommended as the only means of acquiring a real colloquial knowledge of modern languages.
5. Mathematics. (a) Can general mathematical teaching be given to boys who intend to become engineers in such a way as to help them later on in the practical use of mathematics—such a method of teaching naturally differing much from the method	Per Cent. (a) In favour 85 Not in favour 15 100

QUESTION.	SUMMARY OF REPLIES.												
5. Mathematics—<i>continued</i>, which would be used if mathematics were to be merely an intellectual exercise, not actually employed later on in real life, nor even used for the sake of passing an examination?	Per Cent.												
(It has to be remembered that in the great majority of cases the boys whose natural bent is towards engineering find the geometrical side of mathematics fairly easy, but have difficulties with its analytical side. It is considered desirable also that boys leaving school for Engineering training should have more than the mere minimum represented by four Books of Euclid, etc. They ought certainly to know something about Logarithms and the elements of Trigonometry, and also about Similar Figures. It is thought that ample opportunity for such teaching could be found by the omission of the matters mentioned in (5) below.)													
(b) Is it desirable that the teaching of Mathematics at School should be arranged with a view to attain all or any of the following objects?—	(b)												
1. The practical use of arithmetic with the special object of obtaining correct results independently of the mere study of arithmetical methods.	<table> <tr><td>1. Yes</td><td>81</td></tr> <tr><td>No</td><td>19</td></tr> <tr><td></td><td> </td></tr> <tr><td></td><td>100</td></tr> <tr><td></td><td> </td></tr> </table>	1. Yes	81	No	19				100				
1. Yes	81												
No	19												
	100												
2. The encouragement of the use of contracted methods.	<table> <tr><td>2. Yes</td><td>91</td></tr> <tr><td>No</td><td>9</td></tr> <tr><td></td><td> </td></tr> <tr><td></td><td>100</td></tr> <tr><td></td><td> </td></tr> </table>	2. Yes	91	No	9				100				
2. Yes	91												
No	9												
	100												
3. The encouragement of exercises in mental arithmetic.	<table> <tr><td>3. Yes</td><td>94</td></tr> <tr><td>No</td><td>6</td></tr> <tr><td></td><td> </td></tr> <tr><td></td><td>100</td></tr> <tr><td></td><td> </td></tr> </table>	3. Yes	94	No	6				100				
3. Yes	94												
No	6												
	100												
4. The teaching at this stage, of what Prof. Perry has called "Practical Mathematics," of the use of Logarithms, of Elementary	<table> <tr><td>4. Yes</td><td>85</td></tr> <tr><td>No</td><td>10</td></tr> <tr><td>Omit slide-rule</td><td>5</td></tr> <tr><td></td><td> </td></tr> <tr><td></td><td>100</td></tr> <tr><td></td><td> </td></tr> </table>	4. Yes	85	No	10	Omit slide-rule	5				100		
4. Yes	85												
No	10												
Omit slide-rule	5												
	100												

QUESTION.	SUMMARY OF REPLIES.																						
5. Mathematics—continued. Trigonometry (limited, for example, to right-angled triangles), of the general ideas of Projective Geometry, including points and lines at infinity, and the use of the slide-rule. 5. The elimination from instruction in Mathematics of such matters as Cube Root Extraction and elaborate Algebraic Equations, which are purely intellectual gymnastics without any direct usefulness.	Per Cent. <table> <tr> <td>5. Yes</td><td>90</td></tr> <tr> <td>No</td><td>10</td></tr> <tr> <td></td><td style="border-top: 1px solid black;">100</td></tr> </table>	5. Yes	90	No	10		100																
5. Yes	90																						
No	10																						
	100																						
6. Science. (a) Is it better that boys should be made superficially familiar with the general language and ideas of Elementary Physics and Chemistry, or that they should be carried somewhat further in one particular section of such work? (b) Would it be advisable rather to encourage the general study of what used to be known as "Natural Philosophy" as a subject of general mental training as well as of practical interest? (It has been a matter of common complaint among Engineering Professors that in many cases the mechanical ideas imbibed by schoolboys have done more harm than good in their subsequent study of the subject. If, however, it were possible to give schoolboys a thorough grounding in the elements of Mechanics, it would, of course, be useful.) (c) In view of the results hitherto obtained, would it be well to omit Theoretical Mechanics altogether from school teaching?	<table> <tr> <td></td><td style="text-align: right;">Per Cent.</td></tr> <tr> <td>(a) Recommend former</td><td>67</td></tr> <tr> <td> " latter</td><td>23</td></tr> <tr> <td> " both conjointly</td><td>10</td></tr> <tr> <td></td><td style="border-top: 1px solid black;">100</td></tr> <tr> <td>(b) Yes</td><td>78</td></tr> <tr> <td>No</td><td>22</td></tr> <tr> <td></td><td style="border-top: 1px solid black;">100</td></tr> <tr> <td>(c) Yes</td><td>77</td></tr> <tr> <td>No</td><td>23</td></tr> <tr> <td></td><td style="border-top: 1px solid black;">100</td></tr> </table>		Per Cent.	(a) Recommend former	67	" latter	23	" both conjointly	10		100	(b) Yes	78	No	22		100	(c) Yes	77	No	23		100
	Per Cent.																						
(a) Recommend former	67																						
" latter	23																						
" both conjointly	10																						
	100																						
(b) Yes	78																						
No	22																						
	100																						
(c) Yes	77																						
No	23																						
	100																						

QUESTION.	SUMMARY OF REPLIES.
7. Practical Work. (a) How far has it been found desirable that schoolboys should have, as a school exercise, practice in ordinary handicraft work, such as Carpentry or Turning? (b) To what extent has it been found better and more useful, to make the "practical" work really into Laboratory Exercises or Experiments, whether Physical, Chemical, or Mechanical?	Per Cent. (a) Undesirable as a school exercise . . . 44 Desirable . . . 38 Desirable in some cases, } or to a limited extent } 18 <u>100</u> In many cases it is recommended that the boys should be encouraged to take up handicraft work, as a recreation, out of school hours. Per Cent. (b) Consider it desirable and practicable . . . } 38 Consider it desirable . . . 42 Do not recommend this } method . . . } 20 <u>100</u>
8. Drawing. What are your views as to the following schemes of instruction in Drawing to be taught in school to boys who are going afterwards into Engineering? (a) The ordinary teaching of Geometrical Drawing with orthographic projection, including especially curve drawing, both by co-ordinates and by purely projective methods. (b) Free-hand Drawing from ordinary drawing-class models or from solids representing simple details of an engineering character. (c) The drawing, in orthographic projection, of objects from actual measurement, a subject which has been called Practical Mensuration.	Per Cent. (a) Desirable . . . 92 Undesirable . . . 8 <u>100</u> (b) Desirable . . . 96 Undesirable . . . 4 <u>100</u> (c) Desirable . . . 83 Undesirable . . . 17 <u>100</u>
9. Surveying. Is it desirable, and, if so, is it possible, to include anything like instruction in simple chain surveying, without optical instruments, for boys during their school period?	Per Cent. Undesirable . . . 53 Possible and desirable . . . 31 Desirable . . . 16 <u>100</u>

APPENDIX II.

SCHEDULE OF OPINIONS AND QUESTIONS RELATING TO TRAINING IN OFFICES, WORKSHOPS, FACTORIES, OR ON WORKS; AND IN TECHNICAL COLLEGES AND UNIVERSITIES; WITH A SUMMARY OF THE REPLIES RECEIVED.

Comments and replies are invited upon the following opinions and questions. In making them it is requested that answers be given with special reference to boys of average ability, who are destined for the Engineering Profession and who have sufficient means to go through a full course of training.

Alternative suggestions will be welcomed and will receive full consideration.

OPINION OR QUESTION.	SUMMARY OF REPLIES.
1. The Committee are of opinion that the age for leaving school should be about 17 years.	Per Cent.
	Agree 70
	Prefer Sixteen 17
	Prefer Eighteen 7
	Prefer Fifteen 4
	Other replies 2
	100
2. (a) The Committee are of opinion that it is desirable that the course of training for all branches of Engineering should include at least one year's training in Mechanical Engineering workshops, where, ordinarily, information would be gained of the practical applications of electricity. (This is referred to hereafter as the " <i>introductory workshop course</i> .")	Per Cent.
	(a) Agree 72
	One year too short 21
	Do not agree 4
	Other replies 3
	100
(b) The Committee think that this introductory workshop course should be taken at an early period—either previously to the commencement of College training, or after that portion of the College training which is common to all branches of Engineering (<i>see 6 below</i>) has been completed.	
	(b) Agree 33
	Before College 47
	After common portion 10
	Complete College first 5
	Alternating with College 3
	Other replies 2
	100

OPINION OR QUESTION.	SUMMARY OF REPLIES.														
3. The Committee are of opinion that during this (and any subsequent) course of training in workshops, boys should keep the regular working hours, including early morning attendance, and should be treated like ordinary apprentices, and be paid wages.	<table> <tr> <td></td><td>Per Cent.</td></tr> <tr> <td>Agree</td><td>79</td></tr> <tr> <td>Do not agree entirely</td><td>8</td></tr> <tr> <td>Shorter hours if attending evening classes</td><td>7</td></tr> <tr> <td>Should not be paid wages</td><td>5</td></tr> <tr> <td>Other replies</td><td>1</td></tr> <tr> <td></td><td><u>100</u></td></tr> </table>		Per Cent.	Agree	79	Do not agree entirely	8	Shorter hours if attending evening classes	7	Should not be paid wages	5	Other replies	1		<u>100</u>
	Per Cent.														
Agree	79														
Do not agree entirely	8														
Shorter hours if attending evening classes	7														
Should not be paid wages	5														
Other replies	1														
	<u>100</u>														
4. Is it desirable, having regard to the age and physical development of the boys— (a) To require them to attend classes for evening study during this introductory workshop course; or, (b) That this period should be devoted entirely to practical work—ordinary educational work being meanwhile suspended?	<table> <tr> <td>(a) and (b)</td><td>Per Cent.</td></tr> <tr> <td>Former preferable</td><td>55</td></tr> <tr> <td>Latter preferable</td><td>35</td></tr> <tr> <td>Former, with shorter working hours</td><td>3</td></tr> <tr> <td>Depends on individuals</td><td>2</td></tr> <tr> <td>Other replies</td><td>5</td></tr> <tr> <td></td><td><u>100</u></td></tr> </table>	(a) and (b)	Per Cent.	Former preferable	55	Latter preferable	35	Former, with shorter working hours	3	Depends on individuals	2	Other replies	5		<u>100</u>
(a) and (b)	Per Cent.														
Former preferable	55														
Latter preferable	35														
Former, with shorter working hours	3														
Depends on individuals	2														
Other replies	5														
	<u>100</u>														
5. Assuming such an introductory workshop course to be approved for all boys, is it recommended— (a) That it should be followed by a period of study in a technical College or University before specialisation in particular branches of engineering is undertaken; or, (b) Is it considered preferable that this workshop course should be at once followed by a period of practical training in the branch of engineering for which the boy is intended; or,	<table> <tr> <td>(a) and (b)</td><td>Per Cent.</td></tr> <tr> <td>Former preferable</td><td>64</td></tr> <tr> <td>Latter preferable</td><td>31</td></tr> <tr> <td>Other replies</td><td>5</td></tr> <tr> <td></td><td><u>100</u></td></tr> </table>	(a) and (b)	Per Cent.	Former preferable	64	Latter preferable	31	Other replies	5		<u>100</u>				
(a) and (b)	Per Cent.														
Former preferable	64														
Latter preferable	31														
Other replies	5														
	<u>100</u>														

OPINION OR QUESTION.	SUMMARY OF REPLIES.				
5.—continued. (c) Is it deemed desirable that the period of College study should be arranged so as to alternate with the workshop or other practical training—and, if so, in what manner?					Per Cent.
	(c)	Desirable	63		
		Undesirable	29		
		Difficult to arrange	5		
		Desirable in some cases	1		
		Other replies	2		
			100		
Of those who consider the course indicated in (c) desirable, 42 per cent. recommend attendance at College during the winter 6 months, and at the workshop during the summer 6 months, in each year.					
6. The Committee are of opinion that the earlier course of College study should be arranged so as to be common to all branches of engineering. This being assumed— (a) How long a period should be assigned to such common course of study? (b) What is a reasonable total period of College study for a boy of average ability?			(a)	(b)	
			Per Cent.	Per Cent.	
	One session		38	2	
	One or two sessions		6	..	
	Two sessions		42	15	
	Two or three sessions		2	7	
	Three sessions		5	51	
	Three or four sessions		1	9	
	Four sessions		2	11	
	Four or five sessions		..	1	
	Five sessions		..	1	
	Other replies		4	3	
			100	100	
7. To what extent should College study be carried, in (a) Mathematics? (b) Geometrical Drawing? (c) Physics? (d) Chemistry? (e) Geology?	(a)	(b)	(c)	(d)	(e)
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Recommend standards comparable with that of B.Sc. (in Engineering) of London University	54	10	11	8	7
The more the better	23	23	27	18	15
Advanced instruction	13	32	28	23	12
Elementary instruction	..	17	18	18	34
Should be taught with regard to its application in engineering	..	9	..	2	5
Include laboratory	..	..	6	20	..
Should be optional	..	..	..	..	15
Other replies	10	9	10	11	12
	100	100	100	100	100

OPINION OR QUESTION.	COMMENT OR ANSWER.																																																												
8. Apart from the introductory workshop course, what is considered to be a reasonable total period of practical training on works, in factories, workshops, mines, etc., when the age of specialisation is reached?	<table><tr><td></td><td>Per Cent.</td></tr><tr><td>One year</td><td>4</td></tr><tr><td>One to two years</td><td>3</td></tr><tr><td>Two years</td><td>21</td></tr><tr><td>Two to three years</td><td>11</td></tr><tr><td>Three years</td><td>31</td></tr><tr><td>Three to four years</td><td>5</td></tr><tr><td>Four years</td><td>8</td></tr><tr><td>Four to five years</td><td>1</td></tr><tr><td>Five years</td><td>4</td></tr><tr><td>Over 5 years</td><td>3</td></tr><tr><td>Other replies</td><td>9</td></tr><tr><td></td><td>100</td></tr></table>		Per Cent.	One year	4	One to two years	3	Two years	21	Two to three years	11	Three years	31	Three to four years	5	Four years	8	Four to five years	1	Five years	4	Over 5 years	3	Other replies	9		100																																		
	Per Cent.																																																												
One year	4																																																												
One to two years	3																																																												
Two years	21																																																												
Two to three years	11																																																												
Three years	31																																																												
Three to four years	5																																																												
Four years	8																																																												
Four to five years	1																																																												
Five years	4																																																												
Over 5 years	3																																																												
Other replies	9																																																												
	100																																																												
9. In cases where boys complete their College training before beginning their practical training, what is thought best—considering that they must now be about 21 years of age— (a) In regard to the introductory workshop course? (b) In regard to the period required for specialisation in particular branches of engineering? (c) In regard to hours of work and payment of wages in workshops, drawing-offices, mines, works, etc., during such period of specialisation? Would your suggestions in the foregoing respects differ, and, if so, to what extent in cases where practical training preceded or alternated with the College course?	<table><tr><td></td><td>(a)</td><td>(b)</td><td>(c)</td></tr><tr><td></td><td>Per Cent.</td><td>Per Cent.</td><td>Per Cent.</td></tr><tr><td>Same as if taken earlier</td><td>33</td><td>33</td><td>76</td></tr><tr><td>May be shortened</td><td>4</td><td>1</td><td>..</td></tr><tr><td>Should be omitted</td><td>26</td><td>..</td><td>..</td></tr><tr><td>One year</td><td>19</td><td>5</td><td>..</td></tr><tr><td>Eighteen months</td><td>2</td><td>3</td><td>..</td></tr><tr><td>Two years</td><td>5</td><td>17</td><td>..</td></tr><tr><td>Two to three years</td><td>..</td><td>5</td><td>..</td></tr><tr><td>Three years</td><td>3</td><td>19</td><td>..</td></tr><tr><td>Four years</td><td>..</td><td>4</td><td>..</td></tr><tr><td>Until proficient</td><td>..</td><td>2</td><td>..</td></tr><tr><td>Wages should be higher</td><td>..</td><td>..</td><td>10</td></tr><tr><td>Other replies</td><td>8</td><td>11</td><td>14</td></tr><tr><td></td><td>100</td><td>100</td><td>100</td></tr></table> With only a few exceptions, the replies to this question are all in the negative. Entire disapproval of the course referred to in (9) is expressed in more than 50 per cent. of the replies.		(a)	(b)	(c)		Per Cent.	Per Cent.	Per Cent.	Same as if taken earlier	33	33	76	May be shortened	4	1	..	Should be omitted	26	..	..	One year	19	5	..	Eighteen months	2	3	..	Two years	5	17	..	Two to three years	..	5	..	Three years	3	19	..	Four years	..	4	..	Until proficient	..	2	..	Wages should be higher	..	..	10	Other replies	8	11	14		100	100	100
	(a)	(b)	(c)																																																										
	Per Cent.	Per Cent.	Per Cent.																																																										
Same as if taken earlier	33	33	76																																																										
May be shortened	4	1	..																																																										
Should be omitted	26	..	..																																																										
One year	19	5	..																																																										
Eighteen months	2	3	..																																																										
Two years	5	17	..																																																										
Two to three years	..	5	..																																																										
Three years	3	19	..																																																										
Four years	..	4	..																																																										
Until proficient	..	2	..																																																										
Wages should be higher	..	..	10																																																										
Other replies	8	11	14																																																										
	100	100	100																																																										

OPINION OR QUESTION.	COMMENT OR ANSWER.				
	(a)	(b)	(c)	(d)	(e)
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
10. Is it desirable to provide, and, if so, on what scale, in technical Colleges, appliances and equipment for instructing students in—	Yes; in general, scale to be limited only by the funds at disposal				
(a) Engineering drawing?	No	80	48	86	69
(b) Workshop practice?	Doubtful	6	36	2	10
(c) Testing materials or structures?	On small scale only	..	9	..	9
(d) Metallurgical processes?	Moderate equipment	..	..	8	..
(e) Other practical operations incidental to engineering works?	In some Colleges	..	..	..	2
	To teach principles	6	3	..	7
	To illustrate lectures	2	2	1	1
	Include principles of design	3	..	..	..
	Other replies	3	2	3	3
	100	100	100	100	100
					Per Cent.
					91
					2
					2
					2
					3
					100
					Per Cent.
					83
					5
					2
					3
					1
					6
					100

OPINION OR QUESTION.	COMMENT OR ANSWER.	Per Cent.
13. The Committee are of opinion that the improvement of Engineering Education depends greatly on the attitude of employers towards the suggestions foreshadowed in this memorandum; and the Committee would especially urge upon employers the importance of extending facilities to Engineering students for the prosecution of post-graduate work.	Agree	74
	Do not agree	4
	Employers willing to grant facilities	7
	Students must show themselves } capable }	4
	Difficulties in the way	3
	Other replies	8
		100

INDEX

- ACCUMULATOR, electrical, 95
 - hydraulic, 95, 96
- Accuracy, 3, 117, 127, 128, 137, 141, 143, 148, 151, 155, 156, 158
- Acid, nitric, 106
 - process, 43
 - sulphuric, 21, 32, 106
- Acids, 48, 168
- After-blow, 38
- After-filling, 83
- Air, 2, 23, 24
 - compressed, 98, 145
- Alkalies, 68
- Allen, Son & Co. Ltd., Messrs. W. H., 10
- Alloys, 167
 - copper, 46, 55, 123
 - tin, 49
 - zinc, 4
- Alumina, 23, 68, 69
- Aluminium, 49, 81, 94
- Angles, 121, 123
 - cutting, 139, 142
 - re-entrant, 148
- Annealing, 31, 105
- Antimony, 49, 50
- Apprentice, 64
- Architect, 124, 155
- Asbestos, 170

- BACKLASH, 137, 150
- Balls, 152
- Bars, 52, 57, 59, 71
- Basic process, 38, 43
- Beams, 55
- Bearings, 48, 59, 148, 156, 157, 165
 - ball, 101

- Belts, 2
- Bending, 149
- Bessemer, Sir H., 36, 38, 43
 - converter, 36, 38
 - steel, 30, 101
- Best, best best, treble best, 35
- Blau-gas, 94
- Blister steel, 41
- Blowholes, 30, 81, 82, 86
- Blows, 18
- Bodies, hollow, 71
 - prismatic, 124
- Boilers, 23, 27, 60, 97
- Bolts, 5, 58, 60, 61, 166, 169
- Borax, 93, 168
- Boring, 130, 131, 132, 134, 135, 136
 - bar, 132, 143, 151
- Boxes, moulding, 64, 71
- Brass, 4, 46, 47, 49, 52, 53, 54, 167, 170
- Brazing, 46, 167, 168
- Brick dust, 110
- Bricks, 70
- Bridge, 56
- British Association thread, 169
- Bronze, 4, 7, 47, 49, 52, 172
 - aluminium, 49
 - phosphor, 48, 58
- Bulk, production in, 17, 104
- Bulk-T's, 58
- Burring, 166

- CABINETMAKER, 155
- Calipers, 51, 156, 158
- Canada, 21, 22
- Canvas, 170

- Capital outlay, 114, 159
- Carbide, 102, 103, 104, 120
 - silicon, 147
- Carbon, 25, 28, 29, 30, 31, 33, 37, 38, 39, 41, 43, 92, 93, 103, 105, 110
 - dioxide, 22, 25
 - monoxide, 25
 - hardening, 102, 103, 120
 - solution, 104
- Carborundum, 147, 148
 - wheels, 109, 148
- Casehardening, 109, 110
- Cast iron, 62, 79, 88, 153
- Cast steel, 42, 43, 53, 55, 62
- Casting, 20, 49, 55, 64, 65, 123
- Casting ladles, 37
- Castings, 4, 5, 31, 49, 88, 89, 113, 114, 115, 148
 - chilled, 30, 153
 - solid, 71
 - grey, 79
 - weight of, 86
- Catalogues, 6
- Caulking, 98, 111
- Cement, 129
- Cementation, 41, 101, 110
- Centre, 149
 - dab, 145
 - lines, 8
- Centreing, 149
- Chalk, 110, 162
 - marks, 125
- Charcoal, 53, 105, 110
- Charging, 79
- Chemistry, 14
- Chilling, 30, 82
- Chips, 122
- Chromium, 44, 120
- Circles, 7
- Circular motion, 129, 130, 169
- Class, evening, 6
- Clay, 110
- Clearance, 150, 160
- Clutch couplings, 150
 - magnetic, 152
- Coal, 22
- Cocks, 4
- Coke, 22, 23, 24
- Cold-short, 33
- Colours, glowing, 104, 109, 167
 - hardening, 108
- Concave surfaces, 150
- Conditions, mechanical, 3
- Cone and Cup, 24, 26
- Constructional work, 1, 99
- Contraction, 20, 79, 81, 82, 83, 98, 104
- Converter, Bessemer, 36, 37, 38
- Convex surfaces, 150
- Cooling, 106, 117, 135
- Copper, 4, 46, 47, 48, 49, 50, 52, 53, 54, 58, 122, 153, 170
 - alloys, 46, 55
- Corebox, 71, 72, 87
- Cored holes, 87
- Core-maker, 86
- Cores, 64, 70, 71, 72, 73, 74, 80, 84, 85, 86, 87
- Cornwall, 22
- Corundum, 109
- Cost, 51, 53, 86, 90, 91, 111, 128
- Cotters, 168
- Cowper stoves, 27
- Cracks, 86, 110
- Cranes, 94, 98
- Cranks, 60, 89, 165, 166
- Crosshead, 88
- Crucible, 41, 42, 43, 53, 54, 101
- Crystalline, 33
- Cup and Cone, 24, 26
- Cupola, 78
- Curves, 99, 148
- Cut, speed of, 133, 153
- Cutters, 135, 139, 141, 143, 151
 - backed-off, 142, 143
 - cylindrical, 141
- Cutting, 18, 19, 118
 - capacity, 146
 - speed, 147
- Cylinder oil, 63, 115
- Cylinders, 157

- DEFORMATION, 15, 16
 Delta metal, 49, 53, 54, 58
 Depth of cut, 119
 Design, 3, 134
 Detachable blades, 75
 Diameter, 75
 Diamond and holder, 152
 Die forgings, 94
 Dies, 59, 60, 94, 95, 97
 Dimension lines, 8
 Distortion, 110, 115
 Dolomite, 40
 Dovetailed grooves, 86
 Dowels, 67, 70
 Drawing, 1, 3, 6, 7, 8, 19, 58, 59, 60, 67, 161
 Dressing, 84, 86
 Drill, 145, 151, 152
 flat pointed, 151
 radial, 144, 154
 sensitive, 144
 socket, 145
 twist, 150, 152
 Drilling, 111, 112, 143
 machines, 98
 Ductility, 17, 18, 28, 32, 46
 Dust, 148

 EDGE, 67
 Education and training of engineers, 173
 Efficiency, 2, 3, 125, 171
 Elastic limit, 16, 17, 19, 33, 48, 53, 54
 Elasticity, 15, 16, 104, 105, 123
 Electrical engineer, 98
 Electricity, 27, 93, 95, 145
 Electrolysis, 46
 Electromagnet, 137
 Emery, 147, 148
 Energy, 1, 2, 3
 Engine, frame of an, 56
 governor, 172
 parts, 113
 Engines, 1, 2, 49, 114, 125, 126, 165, 171

 Engineer, 156
 Engineering Standards Committee, 58
 Elongation, 16, 17, 48, 54
 Erecting shop, 164
 Erection, 3, 5, 164
 Error, 142, 156, 158, 162, 165
 Expansion, 117
 Extension, 16
 Eye, 158

 FACING, 131, 132, 133, 143
 Fan, 79
 Fans, suction, 148
 Faults, 126
 Feed, 119, 129
 Feel, personal, 157, 159
 Ferro-manganese, 43
 -silicon, 43
 File, 79, 80
 Finishing, 153
 Firebrick, 25
 Fit, easy, good, tight, 160
 Fits, 143, 158, 159
 Fittings, 3, 60, 62, 113, 164
 Flanges, 58, 85, 167
 Flaws, 84
 Fluidity, 79, 81, 83
 Fluids, hardening, 106, 107
 Fluorspar, 93
 Fluxes, 23, 24, 25, 93, 168
 Flywheel, 133
 Forces, 84
 Forged surfaces, 89
 Forgings, 4, 5, 19, 88, 89, 90, 91, 114, 123, 161, 162
 Foundry, 5, 52, 53, 64, 68, 88
 experience, 67
 Fracture, 17, 115
 Frame, 127
 Friction, 3, 50, 117
 Fuel, 79, 80
 Furnace, 60
 airtight, 93
 blast, 22, 23, 24, 26, 36, 78

Furnace, electric, 42
 regenerative, 39, 42

Fusibility, 80

GANTRY, 149

Gas, 1, 3, 20, 23, 24, 30, 39, 69, 70,
 79, 81, 82, 97, 169

absorbing, 81

engine, 55

fire, 39

Gauge, 58, 121, 150, 161, 162

caliper, 158

end, 157

inside, 159

limit, 159, 160

micrometer, 156

plug, 157, 159

ring, 157, 158, 159

screw, 160

thread, 161

Gear-wheels, 124

Germany, 22

Git, 66, 79, 87

Glass, 93, 110

hard, 104, 107

powder, 168

Glow, red, 105

Glue, 110

Good old custom, 160

Grain, 32

Graphite, 31, 43, 103

Grey, 32, 103

Grinding, 109, 120, 121, 138

action, 148

wet, 148

Grindstone, 147

Grooves, 150

Guide screw, 132

Gum, 106

arabic, 110

Gun metal, 47, 49, 50

Gut, 66

HAMMERING, 45

Handwork, value of, 165

Handrail, 62

Hardening difficulties, 139

room, 101

Hardness, 18, 19, 28, 47, 104, 112,
 120, 121, 122, 123, 138

Header, 82

Headstock, loose, 149

Heat, 90, 91, 97, 148

latent, 106

Helves, 34

Hemp, 170

Hexagon, 150, 169

High speed, 116, 155

Holes, arrangement of, 144

Horn shavings, 110

Humours, 126

INDIA, 21

India rubber, 15, 16, 170

Inorganic substances, 110

Institutions, engineering, 17

Iron, 4, 16, 20, 22, 23, 24, 25, 28,
 30, 31, 32, 34, 39, 49, 52, 53,
 54, 55, 56, 57, 58, 60, 62, 79,
 88, 89, 92, 93, 102, 103, 111,
 123, 172

oxide, 68

Ironstone, 21

JIG, 115, 144

Joints, 5, 6, 56, 97, 169

Journals, 128, 156

KEYS, 5, 169

Keyway, 169

Kilns, 22

Knowledge, scientific, 14

Knuckle thread, 169

LABYRINTH PACKING, 170

Lathes, 130, 131, 143, 146, 149,
 153, 154

turret, 133, 134, 136

turning, 74, 90

Lead, 16, 52, 167, 170

- Leather, 170
- Lime, 23, 28, 68, 106
- Limestone, 23
- Lincolnshire, 22
- Linear motion, 129
- Loading capacity, 130
- Loam, 70, 74, 76, 110
- Low speed of cut, 146

- MACHINE, capacity of a, 101**
 - automatic, 134
 - boring, 130, 153
 - drilling, 143, 144, 151, 153
 - grinding, 130, 146, 152
 - milling, 130, 138, 139, 146, 150, 153, 157
 - planing, 138, 139
 - portable, 144, 172
 - shaping, 130
 - shop, 113, 114, 164
 - slotting, 130, 136, 138, 139
- Machines, 1, 2, 74, 77, 99, 113, 125, 126, 130, 165, 171
 - and processes, 113
 - working of, 125
- Machining, 3
- Magnetite, 21
- Malleability, 19, 58
- Mandrel, 50, 55, 59
- Manganese, 20, 29, 38, 42, 102, 103
 - dioxide, 93
 - pig iron, 102, 103
- Marking-off, 99, 114, 155, 161, 162
 - table, 167
- Material, raw, 5, 14, 50, 51, 53, 54, 56, 90, 113, 114
- Measuring, 113, 124, 155, 156
- Mechanical hammers, 95
 - processes, 165
- Mechanism, 123, 126
- Melting, 64, 78
 - point, 28, 36, 39, 167
- Metals, 1, 3, 4, 44, 45, 48, 65, 106
- Method of working, 99
- Middlesborough, 31

- Mills, 57
- Milling, 2, 130, 137
 - circular, 143
 - cutters, 140, 141, 152
- Mineral oil, thin fluid, 63
 - thick fluid, 63
- Motion, 1, 129
- Motor car industry, 61
- Mould, 4, 20, 31, 37, 64, 65, 69, 71
- Moulder, 52, 66
- Moulding boxes, 69, 70, 71, 87

- NITROGEN, 25**
- Noise, 96
- North America, 21
- Northamptonshire, 22
- Notebook, 85
- Nuts, 58, 60, 61, 160

- OBSERVATION HINTS, 85, 111, 149, 171, 172**
- Oil, 106, 107
 - channels, 50
 - grooves, 172
 - pumps, 63
- Ore, 21, 22, 24, 25, 30, 32
- Organic substances, 68, 110
- Osmose, 82
- Ovens, 33
- Oxidation, 91, 92, 33
- Oxide, 107
 - films, 107
- Oxygen, 21, 22, 23, 25, 92
- Oxyhydrogen flame, 93

- PACKING, 169, 170**
 - pieces, 125
- Pattern, 4, 5, 64, 65, 68, 71, 73, 85, 87
 - taper of, 66, 67
 - maker, 68
 - shop, 64, 68, 85
- Permanent set, 17
- Perspective, 7
- Peruvian bark, 110
- Phosphor bronze, 48, 53, 54, 58

- Phosphorus, 20, 21, 33, 37, 38, 40,
 48, 81
 Photography, 6, 8
 Piecework, 121
 Pig iron, 27, 29, 30, 31, 34, 36, 39,
 42, 43, 53, 60, 102, 103
 soft, 103
 Piling, 34
 Pipes, 46, 61
 copper, 167
 oil, 167
 water, 167
 Piston, 172
 rings, 172
 rod, 169
 Pitch, 75, 132, 142
 Planers, 153
 Planing, 2, 74, 130, 136, 137, 150
 Plastic, 17
 Plates, 52, 57, 59, 70, 97, 150
 setting, 144
 Play, 160
 Plum bob, 162
 Plummer blocks, 73
 Pneumatic hammers, 95
 Point, boiling, 106
 Polishing, 152
 Potash, 93
 Potassium nitrate, 110
 ferro-cyanide, 93, 110
 Pouring, 69
 Power, 130
 expended, 159
 hammers, 95
 transmission, 2
 Presses, 95, 96
 Pressing, 19, 59, 60, 166, 168
 Pressure, hydraulic, 98, 168
 Price, 4, 5, 45, 49, 53, 54, 55, 56, 154
 Prints, 6, 8, 73, 161
 Projections, 7
 Propeller, 75, 76, 85
 Properties, hardening, 106
 Puddle rolls, 34
 Puddling process, 34, 35, 36
 Punching, 111
 Pump, 49, 96
 Pyrites, 21
 QUARTZ, 93
 RAMMING, 70
 Ratchet brace, 164
 Raw material, 113
 Reamer, 143, 144
 Reamering, 143
 Rectilinear motion, 130
 Red lead, 62
 short, 32
 Reduction, 16, 22, 24, 25
 Refinery pig, 34, 43
 Refining process, 34, 36
 Reflection, 107
 Refraction, 107
 Refrigeration, 23
 Regenerator, 40
 Reheating, 34, 45
 Remuneration, 126
 Resin, 110
 Rivet holes, 111, 145
 Riveting, 97, 111
 cold, 165, 166, 168
 hot, 166
 machines, 98
 Rivets, 5, 58, 97, 98
 Rolled sections, 56, 60, 94, 113
 Rolling, 19, 31, 34, 45, 57, 60, 87,
 123
 stock, 56
 Rolls, 58, 99
 large, 152
 Roughing, 153
 Rubbing, 2, 4
 Rust, 148
 Rye meal, 110
 SAL-AMMONIAC, 93, 106, 110, 168
 Salt, common, 93, 106, 110
 Sand, 65, 68, 69, 86
 green, 68, 69, 70, 87
 Sandstone, 108
 Sawdust, 110
 Scale, 85, 162

- Scientific theories, 121
- Scotland, 31
- Scrap, 79
- Scratch proof, 19
- Screw-cutting, 132
 - surface, 76
- Screwing, 134
- Screws, 61, 160, 166
- Seizing, 19, 144
- Setting, 114, 115, 116, 121, 136, 144
- Shafts, 2, 157, 169
- Shape, change of, 15
 - practical, 123, 124, 125
- Shaping, 150
- Shearing machines, 98
- Shipbuilding, 49
- Shocks, 18
- Shop, turning, 149
- Siemens-Martin process, 38, 40, 43, 101
- Silica, 23, 68, 69, 93
- Silicon, 20, 29, 30, 36, 37, 40, 43
- Simplicity, 124
- Sizing, 22
- Sketching, 8, 9
- Slag, 23, 24, 25, 26, 27, 28, 38, 41
 - hammer, 31, 34, 93
- Slotting, 150
- Smelting, 21, 25, 57
- Smith, 90
- Smithy, 5, 88, 89, 91, 101
- Soap, 106, 117, 138, 148
- Soda, 93, 148
- Softness, 18
- Solder, 46, 50, 167, 168
- Sow, 27
- Spanner, 169
- Spectroscope, 37, 38
- Speed, 138
- Spikes, 70
- Spindles, 128
- Spirits, 106
- Springs, 137
- Spur gearing, 98
- Square, 162, 169
- Squeezers, 34
- Standard sections, 57
 - sizes, 51
- Standards, testing, 19
- Starting screws, 112
 - levers, 125
- Stamping, 60
- Steady pins, 172
- Steam, 1, 3, 28, 55, 58, 95
 - hammer, 90
 - pipes, 62
- Steel, 4, 5, 7, 16, 19, 21, 30, 32, 36, 38, 39, 40, 41, 42, 43, 44, 52, 53, 54, 55, 58, 60, 88, 89, 92, 93, 103, 104, 105, 109, 111, 113, 120, 122, 123, 128, 153
 - die, 50, 60
- Stone, 27
- Stoves, heating, 23
- Straight edge, 51, 158, 162
 - lines, 7, 8, 123, 124, 136
- Straw, 108
- Strength, 4, 14, 15, 16, 17, 18, 19, 20, 28, 33, 45, 47, 48, 49, 54, 84, 92, 101, 105, 123, 167
- Stress, internal, 108, 109
 - initial, 86, 104, 105, 106
- Striking board, 74, 75, 76
- Strips, fitting, 73, 74, 85
- Structure, chemical, 15
- Structures, 112
- Studs, 61, 144, 172
- Stuffing box, 170
- Style, 124, 125
- Sulphur, 20, 21, 22, 32, 33, 37
- Superheaters, 99
- Surfaces, 131, 132, 133, 140, 141
 - conical, 124
 - glass hard, 146
 - hardening, 109
 - plane, 128
 - spherical, 152, 158
- Sweden, 21, 22
- TAPER, 149, 150
- Tapped holes, 152

- Temper, unequal, 109
 Temperature, 20, 104, 105, 106
 Tempering, 104, 107, 108, 112, 117,
 121, 138
 Template, 75, 144, 149, 161
 Temporary fastenings, 168, 169
 Tension, 17
 Test, 165, 171
 bending, 111
 pieces, 17
 Testing, 161, 164, 171
 shop, 171
 Thermite, Dr. Goldschmidt's, 94,
 97
 Thomas and Gilchrist, 38
 process, 33, 38, 43
 Time, 116, 133
 Tin, 47, 48, 49, 50, 52, 107
 Tool holder, 136, 137
 maker, 121, 122
 room, 161
 Tools, 85, 98, 101, 112, 113, 114,
 121, 127, 128, 132, 146, 149, 150,
 151, 152, 163, 172
 Tracing, 8
 Transport, 5, 6, 56, 112
 Tube work, 99
 Tubes, 45, 46, 58, 59, 111
 Tungsten, 120
 Turbine, 49, 170
 Turner, 90
 Turning, 2, 122, 130, 131, 134, 135,
 136
 Twyers, 25, 26, 79

 UNIVERSITY COURSE, 99
 Urine, 110

 VALVES, 4, 60, 170, 172
 slide, 172
 Vibration, 2, 96
 Vice, parallel, 144, 150

 Views, 7

 WAGES, rate of, 165
 Warping, 109, 115, 117, 138
 Waster, 69, 80
 Water, 22, 119, 148
 jacket, 25
 pressure, 98
 test, 111
 Wear, 137, 141
 and tear, 141
 Web, crank, 89, 166
 of girder, 58
 Wedge, 124, 150
 Weight, 51, 52, 53, 55, 56, 79, 86,
 111, 154
 Welding, 91, 93, 97, 111, 168
 powder, 93
 Wheel tyres, 94, 166
 Wheels, 2, 85, 138, 150, 169
 cart, 166
 emery, 147
 polishing, 152
 White pig iron, 103
 lead, 62
 metal, 49, 53, 55, 86, 167, 172
 Whitworth, Sir Joseph, 61, 169
 thread, 61
 Wire brushes, 66
 Wood, 4
 chisels, 108
 Work, good and bad, 16
 hand, 91, 97
 Working, 113, 117, 134, 137
 properties, 14
 with one heat, 108
 Workmanship, 3
 Workshop, 15
 Worm wheels, 142

 ZINC, 107, 167, 168
 chloride, 168

*Catalogue of Scientific Publications
and Importations of the D. Van Nostrand Company,
23 Murray Street and 27 Warren Street, New York.*

A B C CODE. (See Clausen-Thue.)

ABBOT, H. L., Gen'l. The Defence of the Seacoast of the United States. Lectures delivered before the U. S. Naval War College. 8vo, red cloth. \$2.00

ABBOTT, A. V. The Electrical Transmission of Energy. A Manual for the Design of Electrical Circuits. *New edition, revised, and entirely rewritten.* Fully illustrated. 8vo, cloth, net, \$5.00

ADAM, P. Practical Bookbinding. With illustrations and figures. Translated from the German by Thomas E. Maw. 8vo, cloth, illustrated. net, \$2.50

ADAMS, J. W. Sewers and Drains for Populous Districts. Embracing Rules and Formulas for the dimensions and construction of works of Sanitary Engineers. 8vo, cloth. . . \$2.50

ADDYMAN, F. T. Practical X-Ray Work. Part I, Historical. Part II, Apparatus and its Management. Part III, Practical X-Ray Work. Illustrated with twelve plates from photographs. 8vo, cloth, illustrated. net, \$4.00

A 1 CODE. (See Clausen-Thue.)

AIKMAN, C. M., Prof. Manures and the Principles of Manuring. 8vo, cloth. \$2.50

ALEXANDER, J. H. Universal Dictionary of Weights and Measures, Ancient and Modern, reduced to the Standards of the United States of America. *New Edition, enlarged.* 8vo, cloth. \$3.50

ALEXANDER, S. A. Broke Down: What Should I Do? A Ready Reference and Key to Locomotive Engineers and Firemen, Round-house Machinists, Conductors, Train Hands and Inspectors. With 5 folding plates. 12mo, cloth. \$1.50

ANDERSON, G. L., A.M. (Captain of U. S. Artillery).

Handbook for the use of Electricians in the operation and care of Electrical Machinery and Apparatus of the United States Sea-coast Defenses. Prepared under the direction of the Lieutenant-General Commanding the Army. With tables, diagrams and illustrations. 8vo, cloth, illustrated. \$3.00

ANDERSON, J. W. Prospector's Handbook. A Guide

for the Prospector and Traveller in search of Metal-bearing or other Valuable Minerals. *Eighth Edition, revised.* 8vo, cloth. . . . \$1.50

ANDERSON, W. On the Conversion of Heat into Work.

A Practical Handbook on Heat-engines. *Third Edition.* Illustrated. 12mo, cloth. \$2.25

ANDÉS, L. Vegetable Fats and Oils: Their Practical

Preparation, Purification and Employment for Various Purposes. Their Properties, Adulteration and Examination. A Handbook for Oil Manufacturers and Refiners, Candle, Soap and Lubricating-oil Manufacturers, and the Oil and Fat Industry in general. Translated from the German. With 94 illus. 8vo, cloth. net, \$4.00

— Animal Fats and Oils. Their Practical Production,

Purification and Uses for a great variety of purposes; their Properties, Falsification and Examination. A Handbook for Manufacturers of Oil and Fat Products, Soap and Candle Makers, Agriculturists, Tanners, etc. Translated by Charles Salter. With 62 illustrations. 8vo, cloth. net, \$4.00

— Drying Oils, Boiled Oil, and Solid and Liquid Driers.

A practical work for manufacturers of Oils, Varnishes, Printing Inks, Oilcloth and Linoleum, Oil-cakes, Paints, etc. 8vo, cloth, illustrated. net, \$5.00

— Iron Corrosion, Anti-fouling and Anti-corrosive

Paints. Translated from the German by Charles Salter. Illustrated with engravings and half-tone cuts. 8vo, cloth. . . .net, \$4.00.

— Oil Colors, and Printers' Ink. A Practical Hand-

book treating of Linseed-oil, Boiled Oil, Paints, Artists' Colors, Lampblack, and Printers' Inks (black and colored). Translated from the German by Arthur Morris and Herbert Robson. With 56 figures and diagrams. 8vo, cloth, 212 pages. net, \$2.50

ANNUAL REPORTS on the Progress of Chemistry for 1904.

Vol. I. Issued by the Chemical Society. 8vo, cloth. . . .net, \$2.00
Vol. II (1905). 8vo, cloth. net, \$2.60

- ARNOLD, E.** *Armature Windings of Direct-Current Dynamos.* Extension and Application of a General Winding Rule. Translated from the original German by Francis B. DeGress, M.E. With numerous illustrations. 8vo, cloth... \$2.00
- ARNOLD, R., Dr.** *Animonin and Animonium Compounds.* A Practical Manual for Manufacturers, Chemists, Gas Engineers and Drysalters. *Second Edition.* 12mo, cloth... \$2.00
- Art of Dyeing Wool, Silk and Cotton.** Translated from the French of M. Hellott, M. Macquer and M. Le Pileur D'Apligny. First published in English in 1789. 8vo, cloth, illustrated, *net*, \$2.00
- ASHE, S. W., and KEILEY, J. D.** *Electric Railways,* Theoretically and Practically Treated; Rolling Stock. With numerous figures, diagrams, and folding plates. 12mo, cloth, illustrated. *net*, \$2.50
— Vol. 2. *Sub-stations and the Distributing System.* *In Press.*
- ATKINSON, A. A., Prof. (Ohio University).** *Electrical and Magnetic Calculations,* for the use of Electrical Engineers and Artisans, Teachers, Students and all others interested in the Theory and Application of Electricity and Magnetism. *Second Edition, revised.* 8vo, cloth, illustrated. *net*, \$1.50
- ATKINSON, P.** *The Elements of Electric Lighting,* including Electric Generation, Measurement, Storage and Distribution. *Tenth Edition, fully revised and new matter added.* Illustrated. 12mo, cloth. \$1.50
— *The Elements of Dynamic Electricity and Magnetism.* *Fourth Edition.* 120 illustrations. 12mo, cloth. . \$2.00
— *Power Transmitted by Electricity and its Application by the Electric Motor,* including Electric Railway Construction. *Fourth Edition, fully revised, new matter added.* 12mo, cloth, illustrated. \$2.00
- AUCHINCLOSS, W. S.** *Link and Valve Motions Simplified.* Illustrated with 29 woodcuts and 20 lithographic plates, together with a Travel Scale, and numerous useful tables. *Fourteenth Edition, revised.* 8vo, cloth. \$2.00
- AYRTON, H.** *The Electrical Arc.* With numerous figures, diagrams and plates. 8vo, cloth, illustrated. \$5.00
- AYRTON, W. E., M.I.C.E.** *Practical Electricity.* A Laboratory and Lecture Course for the first-year students of Electrical Engineering, based on the International Definitions of the Electrical Units. Vol. I, Current, Pressure, Resistance, Energy, Power, and Cells. Completely rewritten and containing many figures and diagrams. 12mo, cloth. \$2.00

- BACON, F. W.** A Treatise on the Richards Steam-engine Indicator, with directions for its use. By Charles T. Porter. Revised, with notes and large additions as developed by American practice; with an appendix containing useful formulæ and rules for engineers. Illustrated. *Fourth Edition.* 12mo, cloth.. \$1.00
- BAKER, Arthur L., Prof. (Univ. of Rochester).** Quaternions.....*In Press.*
- BAKER, M. N.** Potable Water and Methods of Detecting Impurities. *New Edition, revised and largely rewritten.* 16mo, cloth. (*Van Nostrand's Science Series*)..... \$0.50
- BALCH, G. T., Col.** Methods of Teaching Patriotism in the Public Schools. 8vo, cloth..... \$1.00
- BALE, M. P.** Pumps and Pumping. A Handbook for Pump Users. 12mo, cloth..... \$1.50
- BALL, S. R.** Popular Guide to the Heavens. A series of eighty-three plates, many of which are colored and lithographed, with explanatory text and index. Small 4to, cloth, illustrated.
net, \$4.50
- BARBA, J.** The Use of Steel for Constructive Purposes. Method of Working, Applying and Testing Plates and Bars. With a Preface by A. L. Holley, C.E. 12mo, cloth..... \$1.50
- BARKER, A. H.** Graphic Methods of Engine Design. Including a Graphical Treatment of the Balancing of Engines. 12mo, cloth..... \$1.50
- BARNARD, F. A. P.** Report on Machinery and Processes of the Industrial Arts and Apparatus of the Exact Sciences at the Paris Universal Exposition, 1867. 152 illustrations and 8 folding plates. 8vo, cloth..... \$5.00
- BARNARD, J. H.** The Naval Militiaman's Guide. Full leather, pocket size..... \$1.25
- BARRUS, G. H.** Boiler Tests: Embracing the Results of one hundred and thirty-seven evaporative tests, made on seventy-one boilers, conducted by the author. 8vo, cloth. \$3.00
- **Engine Tests: Embracing the Results of over one hundred feed-water tests and other investigations of various kinds of steam-engines, conducted by the author. With numerous figures, tables, and diagrams. 8vo, cloth, illustrated.. \$4.00**
The above two purchased together..... \$6.00

BARWISE, S., M.D. (London). *The Purification of Sewage.* Being a brief account of the Scientific Principles of Sewage Purification and their Practical Application. 12mo, cloth, illustrated. *New Edition*..... *net*, \$3.50

BEAUMONT, R. *Color in Woven Design.* With 32 colored plates and numerous original illustrations. Large, 12mo..... \$7.50

— **W. W.** *Practical Treatise on the Steam-engine Indicator, and Indicator Diagrams.* With notes on Engine Performances, Expansion of Steam, Behavior of Steam in Steam-engine Cylinders, and on Gas- and Oil-engine Diagrams. *Second Edition, revised and enlarged.* 8vo, cloth, illustrated.... *net*, \$2.50

BEECH, F. *Dyeing of Cotton Fabrics. A Practical Handbook* for the Dyer and Student. Containing numerous recipes for the production of Cotton Fabrics of all kinds, of a great range of colors, thus making it of great service in the dye-house, while to the student it is of value in that the scientific principles which underlie the operations of dyeing are clearly laid down. With 44 illustrations of Bleaching and Dyeing Machinery. 8vo, cloth, illustrated..... *net*, \$3.00

— **Dyeing of Woolen Fabrics.** With diagrams and figures. 8vo, cloth, illustrated..... *net*, \$3.50

BECKWITH, A. *Pottery. Observations on the Materials and Manufacture of Terra-cotta, Stoneware, Firebrick, Porcelain, Earthenware, Brick, Majolica, and Encaustic Tiles.* *Second Edition.* 8vo, paper..... 60

BEGTRUP, J., M.E. *The Slide Valve and its Functions.* With Special Reference to Modern Practice in the United States. With numerous diagrams and figures. 8vo, cloth..... \$2.00

BERNTHASEN, A. *A Text-book of Organic Chemistry.* Translated by George M'Gowan, Ph.D. *Fifth English Edition,* revised and extended by author and translator. Illustrated. 12mo, cloth..... *In Press.*

BERRY, W. J. *Differential Equations of the First Species.* 12mo, cloth, illustrated..... *In Press.*

BERSCH, J., Dr. **Manufacture of Mineral and Lake Pigments.** Containing directions for the manufacture of all artificial artists' and painters' colors, enamel colors, soot and metallic pigments. A text-book for Manufacturers, Merchants, Artists and Painters. *Translated from the second revised edition by Arthur C. Wright, M.A.* 8vo, cloth, illustrated. . . . *net*, \$5.00

BERTIN, L. E. **Marine Boilers: Their Construction and Working,** dealing more especially with Tubulous Boilers. Translated by Leslie S. Robertson, Assoc. M. Inst. C. E., M. I. Mech. E., M.I.N.A., containing upward of 250 illustrations. Preface by Sir William White, K.C.B., F.R.S., Director of Naval Construction to the Admiralty, and Assistant Controller of the Navy. *Second Edition, revised and enlarged.* 8vo, cloth, illustrated. . . . *net*, \$5.00

BIGGS, C. H. W. **First Principles of Electricity and Magnetism.** A book for beginners in practical work, containing a good deal of useful information not usually to be found in similar books. With numerous tables and 343 diagrams and figures. 12mo, cloth, illustrated. . . . *net*, \$2.00

BINNS, C. F. **Ceramic Technology. Being Some Aspects of Technical Science as applied to Pottery Manufacture.** 8vo, cloth. . . . *net*, \$5.00

— **Manual of Practical Potting. Compiled by Experts.** *Third Edition, revised and enlarged.* 8vo, cloth. . . . *net*, \$7.50

BIRCHMORE, W. H., Dr. **How to Use a Gas Analysis.** 12mo, cloth, illustrated. . . . *net*, \$1.25

BLAKE, W. H. **Brewer's Vade Mecum. With Tables and marginal reference notes.** 8vo, cloth. . . . *net*, \$4.00

— **W. P.** **Report upon the Precious Metals. Being Statistical Notices of the Principal Gold and Silver producing regions of the world, represented at the Paris Universal Exposition.** 8vo, cloth. . . . *net*, \$2.00

BLAKESLEY, T. H. **Alternating Currents of Electricity.** For the use of Students and Engineers. *Third Edition, enlarged.* 12mo, cloth. . . . *net*, \$1.50

BLYTH, A. W., M.R.C.S., F.C.S. **Foods: Their Composition and Analysis.** A Manual for the use of Analytical Chemists, with an Introductory Essay on the History of Adulterations. With numerous tables and illustrations. *Fifth Edition, thoroughly revised, enlarged and rewritten.* 8vo, cloth. . . . *net*, \$7.50

- BLYTH, A. W., M.R.C.S., F.C.S.,** *Poisons: Their Effects and Detection.* A Manual for the use of Analytical Chemists and Experts, with an Introductory Essay on the Growth of Modern Toxicology. *New Edition*..... *In Press.*
- BODMER, G. R.** *Hydraulic Motors and Turbines.* For the use of Engineers, Manufacturers and Students. *Third Edition, revised and enlarged.* With 192 illustrations. 12mo, cloth..... \$5.00
- BOILEAU, J. T.** *A New and Complete Set of Traverse Tables,* showing the Difference of Latitude and Departure of every minute of the Quadrant and to five places of decimals. 8vo, cloth..... \$5.00
- BONNEY, G. E.** *The Electro-platers' Handbook.* A Manual for Amateurs and Young Students of Electro-metallurgy. 60 illustrations. 12mo, cloth..... \$1.20
- BOOTH, W. H.** *Water Softening and Treatment,* Condensing Plant, Feed Pumps, and Heaters for Steam Users and Manufacturers. 8vo, cloth, illustrated..... *net*, \$2.50
- BOURRY, E.** *Treatise on Ceramic Industries.* A Complete Manual for Pottery, Tile and Brick Works. Translated from the French by Wilton P. Rix. With 323 figures and illustrations. 8vo, cloth, illustrated..... *net*, \$8.50
- BOW, R. H.** *A Treatise on Bracing.* With its application to Bridges and other Structures of Wood or Iron. 156 illustrations. 8vo, cloth..... \$1.50
- BOWIE, AUG. J., Jr., M.E.** *A Practical Treatise on Hydraulic Mining in California.* With Description of the Use and Construction of Ditches, Flumes, Wrought-iron Pipes and Dams; Flow of Water on Heavy Grades, and its Applicability, under High Pressure, to Mining. *Ninth Edition.* Small quarto, cloth. Illustrated..... \$5.00
- BOWKER, Wm. R.** *Dynamo, Motor and Switchboard Circuits.* For Electrical Engineers. A practical book, dealing with the subject of Direct, Alternating, and Polyphase Currents. With over 100 diagrams and engravings. 8vo, cloth.. *net*, \$2.25
- BOWSER, E. A., Prof.** *An Elementary Treatise on Analytic Geometry.* Embracing Plane Geometry, and an Introduction to Geometry of three Dimensions. *Twenty-first Edition.* 12mo, cloth..... *net*, \$1.75

BOWSER, E. A., Prof. *An Elementary Treatise on the Differential and Integral Calculus.* With numerous examples. *Twenty-first Edition.* Enlarged by 640 additional examples. 12mo, cloth.....net, \$2.25

— *An Elementary Treatise on Analytic Mechanics.* With numerous examples. *Sixteenth Edition.* 12mo, cloth...net, \$3.00

— *An Elementary Treatise on Hydro-mechanics.* With numerous examples. *Fifth Edition.* 12mo, cloth.....net, \$2.50

— *A Treatise on Roofs and Bridges.* With Numerous Exercises, especially adapted for school use. 12mo, cloth. Illustrated.....net, \$2.25

BRASSEY'S Naval Annual for 1906. Edited by T. A. Brassey. With numerous full-page diagrams, half-tone illustrations and tables. Twentieth year of publication. 8vo, cloth, illustrated.....net, \$6.00

BRAUN, E. *The Baker's Book: A Practical Handbook of the Baking Industry in all Countries.* Profusely illustrated with diagrams, engravings, and full-page colored plates. Translated into English and edited by Emil Braun. Vol. I., 8vo, cloth, illustrated, 308 pages.....\$2.50
Vol. II. 363 pages, illustrated.....\$2.50

British Standard Sections. Issued by the Engineering Standards Committee, Supported by The Institution of Civil Engineers, The Institution of Mechanical Engineers, The Institution of Naval Architects, The Iron and Steel Institute, and The Institution of Electrical Engineers. Comprising 9 plates of diagrams, with letter-press and tables. Oblong pamphlet, 8 $\frac{1}{2}$ ×15.....\$1.00

BROWN, WM. N. *The Art of Enamelling on Metal.* With figures and illustrations. 12mo, cloth, illustrated. net, \$1.00

— *Handbook on Japanning and Enamelling, for Cycles, Bedsteads, Tinware, etc.* 12mo, cloth, illustrated. net, \$1.50

— *House Decorating and Painting.* With Numerous illustrations. 12mo, cloth.....net, \$1.50

— *History of Decorative Art.* With Designs and Illustrations. 12mo, cloth.....net, \$1.25

BROWN, WM. N. Principle and Practice of Dipping, Burnishing, Lacquering and Bronzing Brass Ware. 12mo, cloth.
net, \$1.00

— Workshop Wrinkles for Decorators, Painters, Paper-Hangers and Others. 8vo, cloth..... net, \$1.00

BUCHANAN, E. E. Tables of Squares. Containing the square of every foot, inch, and sixteenth of an inch, between one sixteenth of an inch and fifty feet. For Engineers and Calculators. 16mo, oblong, cloth..... \$1.00

BULMAN, H. F., and REDMAYNE, R. S. A. Colliery Working and Management; comprising the duties of a colliery manager, the superintendence and arrangement of labor and wages, and the different systems of working coal-seams. With engravings, diagrams, and tables. *Second Edition, revised and enlarged.* 8vo, cloth, illustrated..... net, \$6.00

BURGH, N. P. Modern Marine Engineering, Applied to Paddle and Screw Propulsion. Consisting of 36 colored plates, 259 practical woodcut illustrations and 403 pages of descriptive matter. The whole being an exposition of the present practice of James Watt & Co., J. & G. Rennie, R. Napier & Sons, and other celebrated firms. Thick quarto, half morocco..... \$10.00

BURT, W. A. Key to the Solar Compass, and Surveyor's Companion. Comprising all the rules necessary for use in the field; also description of the Linear Surveys and Public Land System of the United States, Notes on the Barometer, Suggestions for an Outfit for a Survey of Four Months, etc. *Seventh Edition.* Pocket size, full leather..... \$2.50

BUSKETT, E. W. Fire Assaying. 12mo, cloth, illustrated..... *In Press.*

CAIN, W., Prof. Brief Course in the Calculus. With figures and diagrams. 8vo, cloth, illustrated..... net, \$1.75

— Theory of Steel-concrete Arches and of Vaulted Structures. *New Edition, revised and enlarged.* 16mo, cloth, illustrated. (*Van Nostrand Science Series*)..... \$0.50

CAMPIN, F. On the Construction of Iron Roofs. A Theoretical and Practical Treatise, with woodcuts and plates of roofs recently executed. 8vo, cloth..... \$2.00

CARPENTER, Prof. R. C., and DIEDERICH, Prof. H. Internal Combustion Motors. With figures and diagrams. 8vo. cloth, illustrated..... *In Press*,

CARTER, E. T. Motive Power and Gearing for Electrical Machinery. A treatise on the Theory and Practice of the Mechanical Equipment of Power Stations for Electrical Supply and for Electric Traction. *Second Edition*, revised in part by G. Thomas-Davies. 8vo, cloth, illustrated..... \$5.00

CATHCART, WM. L., Prof. Machine Design. Part I. Fastenings. 8vo, cloth, illustrated..... *net*, \$3.00

— Machine Elements; Shrinkage and Pressure Joints. With tables and diagrams..... *In Press*.

— Marine-Engine Design..... *In Press*.

— and CHAFFEE, J. I. Course of Graphic Statics Applied to Mechanical Engineering..... *In Press*

CHAMBER'S MATHEMATICAL TABLES, consisting of Logarithms of Numbers 1 to 108,000, Trigonometrical, Nautical and other Tables. *New Edition*. 8vo, cloth..... \$1.75

CHARPENTIER, P. Timber. A Comprehensive Study of Wood in all its Aspects, Commercial and Botanical. Showing the Different Applications and Uses of Timber in Various Trades, etc. Translated into English. 8vo, cloth, illus... *net*, \$6.00

CHAUVENET, W., Prof. New Method of Correcting Lunar Distances, and Improved Method of Finding the Error and Rate of a Chronometer, by Equal Altitudes. 8vo, cloth. \$2.00

CHILD, C. T. The How and Why of Electricity. A Book of Information for non-technical readers, treating of the Properties of Electricity, and how it is generated, handled, controlled, measured and set to work. Also explaining the operation of Electrical Apparatus. 8vo, cloth, illustrated. \$1.00

CHRISTIE, W. W. Boiler-waters, Scale, Corrosion, Foaming. 8vo, cloth, illustrated. *net*, \$3.00

— Chimney Design and Theory. A Book for Engineers and Architects, with numerous half-tone illustrations and plates of famous chimneys. *Second Edition, revised*. 8vo, cloth. \$3.00

CHRISTIE, W. W. **Furnace Draft: its Production by Mechanical Methods.** A Handy Reference Book, with figures and tables. 16mo, cloth, illustrated. (*Van Nostrand's Science Series*). \$0.50

CLAPPERTON, G. **Practical Paper-making. A Manual** for Paper-makers and Owners and Managers of Paper Mills, to which is appended useful tables, calculations, data, etc., with illustrations reproduced from micro-photographs. 12mo, cloth, illustrated. \$2.50

CLARK, D. K., C.E. **A Manual of Rules, Tables and Data for Mechanical Engineers.** Based on the most recent investigations. Illustrated with numerous diagrams. 1012 pages. 8vo, cloth. *Sixth Edition*. \$5.00

— **Fuel: its Combustion and Economy; consisting of** abridgments of Treatise on the Combustion of Coal. By C. W. Williams, and the Economy of Fuel, by T. S. Prideaux. With extensive additions in recent practice in the Combustion and Economy of Fuel, Coal, Coke, Wood, Peat, Petroleum, etc. *Fourth Edition*. 12mo, cloth. \$1.50

— **The Mechanical Engineer's Pocket-book of Tables, Formulæ, Rules and Data.** A Handy Book of Reference for Daily Use in Engineering Practice. 16mo, morocco. *Fifth Edition, carefully revised throughout*. \$3.00

— **Tramways: Their Construction and Working.** Embracing a comprehensive history of the system, with accounts of the various modes of traction, a description of the varieties of rolling stock, and ample details of Cost and Working Expenses. *Second Edition, rewritten and greatly enlarged, with upwards of 400 illustrations*. Thick 8vo, cloth. \$89.00

CLARK, J. M. **New System of Laying Out Railway Turn-outs instantly, by inspection from tables.** 12mo, cloth. . . \$1.00

CLAUSEN-THUE, W. **The A B C Universal Commercial Electric Telegraphic Code; specially adapted for the use of Financiers, Merchants, Ship-owners, Brokers, Agents, etc.** *Fourth Edition*. 8vo, cloth. \$5.00
Fifth Edition of same. \$7.00

— **The A 1 Universal Commercial Electric Telegraphic Code.** Over 1240 pages and nearly 90,000 variations. 8vo, cloth. \$7.50

- CLEEMANN, T. M.** *The Railroad Engineer's Practice.*
Being a Short but Complete Description of the Duties of the
Young Engineer in Preliminary and Location Surveys and in
Construction. *Fourth Edition, revised and enlarged.* Illustrated.
12mo, cloth..... \$1.50
- CLEVENGER, S. R.** *A Treatise on the Method of Gov-*
ernment Surveying as prescribed by the U. S. Congress and Com-
missioner of the General Land Office, with complete Mathematical,
Astronomical, and Practical Instructions for the use of the
United States Surveyors in the field. 16mo, morocco..... \$2.50
- CLOUTH, F.** *Rubber, Gutta-Percha, and Balata. First*
English Translation with Additions and Emendations by the
Author. With numerous figures, tables, diagrams, and folding
plates. 8vo, cloth, illustrated..... *net*, \$5.00
- COFFIN, J. H. C., Prof.** *Navigation and Nautical Astron-*
omy. Prepared for the use of the U. S. Naval Academy. New
Edition. Revised by Commander Charles Belknap. 52 woodcut
illustrations. 12mo, cloth..... *net*, \$3.50
- COLE, R. S., M.A.** *A Treatise on Photographic Optics.*
Being an account of the Principles of Optics, so far as they apply
to photography. 12mo, cloth, 103 illus. and folding plates..\$2.50
- COLLINS, J. E.** *The Private Book of Useful Alloys and*
Memoranda for Goldsmiths, Jewelers, etc. 18mo, cloth. \$0.50
- COLLINS, T. B.** *The Steam Turbine, or the New Engine.*
8vo, cloth, illustrated..... *In Press.*
- COOPER, W. R., M.A.** *Primary Batteries: Their Con-*
struction and Use. With numerous figures and diagrams. 8vo,
cloth, illustrated..... *net*, \$4.00
- COPPERTHWAIT, WM. C.** *Tunnel Shields, and the*
Use of Compressed Air in Subaqueous Works. With numerous
diagrams and figures. 4to, cloth, illustrated. *net*, \$9.00
- COREY, H. T.** *Water-supply Engineering. Fully illustrated.*
In Press.
- CORNWALL, H. B., Prof.** *Manual of Blow-pipe Analysis,*
Qualitative and Quantitative. With a Complete System of
Determinative Mineralogy. 8vo, cloth, with many illustra-
tions. \$2.50

COWELL, W. B. *Pure Air, Ozone and Water. A Practical Treatise of their Utilization and Value in Oil, Grease, Soap, Paint, Glue and other Industries. With tables and figures.* 12mo, cloth, illustrated. *net*, \$2.00

CRAIG, B. F. *Weights and Measures. An Account of the Decimal System, with Tables of Conversion for Commercial and Scientific Uses.* Square 32mo, limp cloth. 50

CROCKER, F. B., Prof. *Electric Lighting. A Practical Exposition of the Art. For use of Engineers, Students, and others interested in the Installation or Operation of Electrical Plants. Vol. I. The Generating Plant. New Edition, thoroughly revised and rewritten.* 8vo, cloth, illustrated. \$3.00
Vol. II. Distributing Systems and Lamps. Fifth Edition. 8vo, cloth, illustrated. \$3.00

— **and WHEELER, S. S.** *The Management of Electrical Machinery. Being a thoroughly revised and rewritten edition of the authors' "Practical Management of Dynamos and Motors." With a special chapter by H. A. Foster.* 12mo, cloth, illustrated. *net*, \$1.00

CROSSKEY, L. R. *Elementary Perspective: Arranged to meet the requirements of Architects and Draughtsmen, and of Art Students preparing for the elementary examination of the Science and Art Department, South Kensington. With numerous full-page plates and diagrams.* 8vo, cloth, illustrated. . . \$1.00

— **and THAW, J.** *Advanced Perspective, involving the Drawing of Objects when placed in Oblique Positions, Shadows and Reflections. Arranged to meet the requirements of Architects, Draughtsmen, and Students preparing for the Perspective Examination of the Education Department. With numerous full-page plates and diagrams.* 8vo, cloth, illustrated. \$1.50

DAVIES, E. H. *Machinery for Metalliferous Mines. A Practical Treatise for Mining Engineers, Metallurgists and Managers of Mines. With upwards of 400 illustrations. Second Edition, rewritten and enlarged.* 8vo, cloth. *net*, \$8.00

DAVIES, D. C. *A Treatise on Metalliferous Minerals and Mining. Sixth Edition, thoroughly revised and much enlarged by his son.* 8vo, cloth. *net*, \$5.00

— *Mining Machinery.* *In Press.*

DAVISON, G. C., Lieut. *Water-tube Boilers.* *In Press.*

- DAY, C.** *The Indicator and its Diagrams.* With Chapters on Engine and Boiler Testing; including a Table of Piston Constants compiled by W. H. Fowler. 12mo, cloth. 125 illustrations..... \$2.00
- DEITE, Dr. C.** *Manual of Soapmaking, including medicated soaps, stain-removing soaps, metal polishing soaps, soap powders and detergents.* With a treatise on perfumes for scented soaps, and their production and tests for purity and strength. Edited from the text of numerous experts. Translated from the original by S. I. King, F.C.S. With figures. 4to, cloth, illustrated. net, \$5.00
- DE LA COUX, H.** *The Industrial Uses of Water.* With numerous tables, figures, and diagrams. Translated from the French and revised by Arthur Morris. 8vo, cloth.....net, \$4.50
- DENNY, G. A.** *Deep-level Mines of the Rand, and their future development, considered from the commercial point of view.* With folding plates, diagrams, and tables. 4to, cloth, illustrated. net, \$10.00
- DERR, W. L.** *Block Signal Operation. A Practical Manual.* Pocket Size. Oblong, cloth. *Second Edition*.... \$1.50
- DIBDIN, W. J.** *Public Lighting by Gas and Electricity.* With tables, diagrams, engravings and full-page plates. 8vo, cloth, illustrated..... net, \$8.00
- *Purification of Sewage and Water.* With tables, engravings, and folding plates. *Third Edition, revised and enlarged.* 8vo, cloth, illus. and numerous folding plates.... \$6.50
- DIETERICH, K.** *Analysis of Resins, Balsams, and Gum Resins: their Chemistry and Pharmacognosis.* For the use of the Scientific and Technical Research Chemist. With a Bibliography. Translated from the German, by Chas. Salter. 8vo. cloth..... net, \$3.00
- DIXON, D. B.** *The Machinist's and Steam Engineer's Practical Calculator.* A Compilation of Useful Rules and Problems arithmetically solved, together with General Information applicable to Shop-tools, Mill-gearing, Pulleys and Shafts, Steam-boilers and Engines. Embracing valuable Tables and Instruction in Screw-cutting, Valve and Link Motion, etc. *Third Edition.* 16mo, full morocco, pocket form..... \$1.25
- DOBLE, W. A.** *Power Plant Construction on the Pacific Coast*..... *In Press.*

DODD, GEO. Dictionary of Manufactures, Mining, Machinery, and the Industrial Arts. 12mo, cloth. \$1.50

DORR, B. F. The Surveyor's Guide and Pocket Table-book. *Fifth Edition, thoroughly revised and greatly extended.* With a second appendix up to date. 16mo, morocco flaps. . \$2.00

DRAPER, C. H. An Elementary Text-book of Light, Heat and Sound, with Numerous Examples. *Fourth Edition.* 12mo, cloth, illustrated. \$1.00

— **Heat and the Principles of Thermo-dynamics.** With many illustrations and numerical examples. 12mo, cloth. . \$1.50

DYSON, S. S. Practical Testing of Raw Materials. A Concise Handbook for Manufacturers, Merchants, and Users of Chemicals, Oils, Fuels, Gas Residuals and By-products, and Paper-making Materials, with Chapters on Water Analysis and the Testing of Trade Effluents. 8vo, cloth, illustrations, 177 pages. *net*, \$5.00

ECCLES, R. G. (Dr.), and DUCKWALL, E. W. Food Preservatives: their Advantages and Proper Use; The Practical *versus* the Theoretical Side of the Pure Food Problem. 8vo, paper. \$0.50
Cloth. 1.00

EDDY, H. T., Prof. Researches in Graphical Statics. Embracing New Constructions in Graphical Statics, a New General Method in Graphical Statics, and the Theory of Internal Stress in Graphical Statics. 8vo, cloth. \$1.50

— **Maximum Stresses under Concentrated Loads.** Treated graphically. Illustrated. 8vo, cloth. \$1.50

ELSSLER, M. The Metallurgy of Gold. A Practical Treatise on the Metallurgical Treatment of Gold-bearing Ores, including the Processes of Concentration and Chlorination, and the Assaying, Melting and Refining of Gold. *Fifth Edition, revised and greatly enlarged.* Over 300 illustrations and numerous folding plates. 8vo, cloth. \$7.50

— **The Hydro-Metallurgy of Copper.** Being an Account of processes adopted in the Hydro-metallurgical Treatment of Cupriferous Ores, including the Manufacture of Copper Vitriol. With chapters on the sources of supply of Copper and the Roasting of Copper Ores. With numerous diagrams and figures. 8vo, cloth, illustrated. *net*, \$4.50

EISSLER, M. The Metallurgy of Silver. A Practical Treatise on the Amalgamation, Roasting and Lixiviation of Silver Ores, including the Assaying, Melting and Refining of Silver Bullion. 124 illustrations. Second Edition, enlarged. 8vo, cloth. \$4.00

— **The Metallurgy of Argentiferous Lead. A Practical Treatise on the Smelting of Silver-Lead Ores and the Refining of Lead Bullion. Including Reports on Various Smelting Establishments and Descriptions of Modern Smelting Furnaces and Plants in Europe and America. With 183 illustrations. 8vo, cloth, \$5.00**

— **Cyanide Process for the Extraction of Gold and its Practical Application on the Witwatersrand Gold Fields in South Africa. Third Edition, revised and enlarged. Illustrations and folding plates. 8vo, cloth..... \$3.00**

— **A Handbook on Modern Explosives. Being a Practical Treatise on the Manufacture and Use of Dynamite, Gun-cotton, Nitroglycerine, and other Explosive Compounds, including the manufacture of Collodion-cotton, with chapters on Explosives in Practical Application. Second Edition, enlarged with 150 illustrations. 12mo, cloth..... \$5.00**

ELIOT, C. W., and STORER, F. H. A Compendious. Manual of Qualitative Chemical Analysis. Revised with the co-operation of the authors, by Prof. William R. Nichols. Illustrated. Twentieth Edition, newly revised by Prof. W. B. Lindsay. 12mo, cloth..... net, \$1.25

ELLIOT, G. H., Maj. European Light-house Systems. Being a Report of a Tour of Inspection made in 1873. 51 engravings and 21 woodcuts. 8vo, cloth..... \$5.00

ERFURT, J. Dyeing of Paper Pulp. A Practical Treatise for the use of paper-makers, paper-stainers, students and others, With illustrations and 157 patterns of paper dyed in the pulp, with formulas for each. Translated into English and edited, with additions, by Julius Hübner, F.C.S. 8vo, cloth, illustrated..... net, \$7.50

EVERETT, J. D. Elementary Text-book of Physics. Illustrated. Seventh Edition. 12mo, cloth..... \$1.50

EWING, A. J., Prof. The Magnetic Induction in Iron and other metals. Third Edition, revised. 159 illustrations 8vo, cloth..... \$4.00

FAIRIE, J., F.G.S. Notes on Lead Ores: Their Distribution and Properties. 12mo, cloth. \$1.00

— Notes on Pottery Clays: The Distribution, Properties, Uses and Analysis of Ball Clays, China Clays and China Stone. With tables and formulæ. 12mo, cloth. \$1.50

FANNING, J. T. A Practical Treatise on Hydraulic and Water-supply Engineering. Relating to the Hydrology, Hydrodynamics and Practical Construction of Water-works in North America. 180 illus. 8vo, cloth. *Sixteenth Edition, revised, enlarged, and new tables and illustrations added.* 650 pp. \$5.00

FAY, I. W. The Coal-tar Colors: Their Origin and Chemistry. 8vo, cloth, illustrated. *In Press.*

FERNBACH, R. L. Glue and Gelatine; a Practical Treatise on the Methods of Testing and Use. 12mo, cloth. *In Press.*

FISH, J. C. L. Lettering of Working Drawings. Thirteen plates, with descriptive text. Oblong, 9×12½, boards. \$1.00

FISHER, H. K. C., and DARBY, W. C. Students' Guide to Submarine Cable Testing. *Third (new and enlarged) Edition.* 8vo, cloth, illustrated. \$3.50

FISHER, W. C. The Potentiometer and its Adjuncts. 8vo, cloth. \$2.25

FISKE, B. A., Lieut., U.S.N. Electricity in Theory and Practice; or, The Elements of Electrical Engineering. *Eighth Edition.* 8vo, cloth. \$2.50

FLEISCHMANN, W. The Book of the Dairy. A Manual of the Science and Practice of Dairy Work. Translated from the German, by C. M. Aikman and R. Patrick Wright. 8vo, cloth. \$4.00

FLEMING, J. A., Prof. The Alternate-current Transformer in Theory and Practice. Vol. I., The Induction of Electric Currents; 611 pages. *New Edition, illustrated.* 8vo, cloth, \$5.00
Vol. II., The Utilization of Induced Currents. Illustrated. 8vo, cloth. \$5.00

— Centenary of the Electrical Current, 1799–1899. 8vo, paper, illustrated. \$0.50

- FLEMING, J. A., Prof.** *Electric Lamps and Electric Lighting.* Being a course of four lectures delivered at the Royal Institution, April-May, 1894. 8vo, cloth, fully illustrated.....\$3.00
- *Electrical Laboratory Notes and Forms, Elementary and Advanced.* 4to, cloth, illustrated. \$5.00
- *A Handbook for the Electrical Laboratory and Testing Room.* 2 volumes. 8vo, cloth.....each \$5.00
- FLEURY, H.** *The Calculus Without Limits or Infinitesimals.* Translated by C. O. Mailloux. *In Press*
- FOLEY, N., and PRAY, THOS., Jr.** *The Mechanical Engineers' Reference Book for Machine and Boiler Construction, in two parts. Part 1—General Engineering Data. Part 2—Boiler Construction. With 51 plates and numerous illustrations, specially drawn for this work. Folio, half morocco. New Edition.*..... *In Press.*
- FORNEY, M. N.** *Catechism of the Locomotive. Second Edition, revised and enlarged.* 46th thousand. 8vo, cloth..\$3.50
- FOSTER, H. A.** *Electrical Engineers' Pocket-book. With the Collaboration of Eminent Specialists. A handbook of useful data for Electricians and Electrical Engineers. With innumerable tables, diagrams, and figures. Third Edition, revised.* Pocket size, full leather, 1000 pp. \$5.00
- FOSTER, J. G., Gen., U.S.A.** *Submarine Blasting in Boston Harbor, Massachusetts. Removal of Tower and Corwin Rocks. Illustrated with 7 plates.* 4to, cloth..... \$3.50
- FOSTER, J.** *Treatise on the Evaporation of Saccharine, Chemical and other Liquids by the Multiple System in Vacuum and Open Air. Third Edition.* Diagrams and large plates. 8vo, cloth..... \$7.50
- FOX, WM., and THOMAS, C. W., M.E.** *A Practical Course in Mechanical Drawing. Second Edition, revised.* 12mo, cloth, with plates..... \$1.25
- FRANCIS, J. B., C.E.** *Lowell Hydraulic Experiments.* Being a selection from experiments on Hydraulic Motors on the Flow of Water over Weirs, in Open Canals of uniform rectangular section, and through submerged Orifices and diverging Tubes. Made at Lowell, Mass. *Fourth Edition, revised and enlarged,* with many new experiments, and illustrated with 23 copper-plate engravings 4to, cloth. \$15.00

FRASER, R. H., and CLARK, C. H. Marine Engineering.
In Press.

FULLER, G. W. Report on the Investigations into the Purification of the Ohio River Water at Louisville, Kentucky, made to the President and Directors of the Louisville Water Company. Published under agreement with the Directors. 3 full-page plates. 4to, cloth. net, \$10.00

FURNELL, J. Students' Manual of Paints, Colors, Oils and Varnishes. 8vo, cloth, illustrated. net, \$1.00

GARCKE, E., and FELS, J. M. Factory Accounts: their principles and practice. A handbook for accountants and manufacturers, with appendices on the nomenclature of machine details, the rating of factories, fire and boiler insurance, the factory and workshop acts, etc., including also a large number of specimen rulings: *Fifth Edition, revised and extended.* 8vo, cloth, illustrated. **\$3.00**

GEIKIE, J. Structural and Field Geology, for Students of Pure and Applied Science. With figures, diagrams, and half-tone plates. 8vo, cloth, illustrated. net, \$4.00

GERBER, N. Chemical and Physical Analysis of Milk, Condensed Milk, and Infants' Milk-food. 8vo, cloth. \$1.25

GERHARD, WM. P. Sanitary Engineering. 12mo, cloth. \$1.25

GESCHWIND, L. Manufacture of Alum and Sulphates, and other Salts of Alumina and Iron; their uses and applications as mordants in dyeing and calico printing, and their other applications in the Arts, Manufactures, Sanitary Engineering, Agriculture and Horticulture. Translated from the French by Charles Salter. With tables, figures and diagrams. 8vo, cloth, illustrated. net, \$5.00

GIBBS, W. E. Lighting by Acetylene, Generators, Burners and Electric Furnaces. With 66 illustrations. *Second Edition, revised.* 12mo, cloth. \$1.50

GILLMORE, Q. A., Gen. Treatise on Limes, Hydraulic Cements and Mortars. Papers on Practical Engineering, United States Engineer Department, No. 9, containing Reports of numerous Experiments conducted in New York City during the years 1853 to 1861, inclusive. With numerous illustrations. 8vo, cloth. \$4.00

GILLMORE, Q. A., Gen. *Practical Treatise on the Construction of Roads, Streets and Pavements. Tenth Edition.* With 70 illustrations. 12mo, cloth. \$2.00

— *Report on Strength of the Building Stones in the United States, etc.* 8vo, illustrated, cloth. \$1.00

GOLDING, H. A. *The Theta-Phi Diagram. Practically Applied to Steam, Gas, Oil and Air Engines.* 12mo, cloth, illustrated. net, \$1.25

GOODEVE, T. M. *A Text-book on the Steam-engine. With a Supplement on Gas-engines. Twelfth Edition, enlarged.* 143 illustrations. 12mo, cloth. \$2.00

GORE, G., F.R.S. *The Art of Electrolytic Separation of Metals, etc. (Theoretical and Practical.)* Illustrated. 8vo, cloth. \$3.50

GOULD, E. S. *The Arithmetic of the Steam-engine.* 8vo, cloth. \$1.00

— *Practical Hydrostatics and Hydrostatic Formulas.* With numerous figures and diagrams. (*Van Nostrand's Science Series.*) 16mo, cloth, illustrated, 114 pp. \$0.50

GRAY, J., B.Sc. *Electrical Influence Machines: Their Historical Development, and Modern Forms, with instructions for making them. With numerous figures and diagrams. Second Edition, revised and enlarged.* 12mo, cloth, illus., 296 pp. . . . \$2.00

GREENWOOD, E. *Classified Guide to Technical and Commercial Books. Subject List of Principal British and American Works in print.* 8vo, cloth. net, \$3.00

GRIFFITHS, A. B., Ph.D. *A Treatise on Manures, or the Philosophy of Manuring. A Practical Handbook for the Agriculturist, Manufacturer, and Student.* 12mo, cloth. . . \$3.00

— *Dental Metallurgy. A Manual for Students and Dentists.* 8vo, cloth, illustrated, 208 pp. net, \$3.50

GROSS, E. *Hops, in their Botanical, Agricultural and Technical Aspect, and as an article of Commerce. Translated from the German by Charles Salter. With tables, diagrams, and illustrations.* 8vo, cloth, illustrated. net, \$4.50

GROVER, F. *Practical Treatise on Modern Gas and Oil Engines.* 8vo, cloth, illustrated. *net*, \$2.00

GRUNER, A. *Power-loom Weaving and Yarn Numbering*, according to various systems, with conversion tables. An auxiliary and text-book for pupils of weaving schools, as well as for self-instruction, and for general use by those engaged in the weaving industry. Illustrated with colored diagrams. 8vo, cloth. *net*, \$3.00

GURDEN, R. L. *Traverse Tables: Computed to Four-place Decimals for every single minute of angle up to 100 of Distance. For the use of Surveyors and Engineers. New Edition.* Folio, half morocco. \$7.50

GUY, A. E. *Experiments on the Flexure of Beams*, resulting in the Discovery of New Laws of Failure by Buckling. Reprinted from the "American Machinist." With diagrams and folding plates. 8vo, cloth, illustrated, 122 pages. . . . *net*, \$1.25

— **A. F.** *Electric Light and Power: Giving the Result of Practical Experience in Central-station Work.* 8vo, cloth, illustrated. \$2.50

HAEDER, H., C.E. *A Handbook on the Steam-engine.* With especial reference to small and medium-sized engines. For the use of Engine-makers, Mechanical Draughtsmen, Engineering Students and Users of Steam Power. Translated from the German, with considerable additions and alterations, by H. H. P. Powles. *Third English Edition, revised.* 8vo, cloth, illustrated, 458 pages. \$3.00

HALL, C. H. *Chemistry of Paints and Paint Vehicles.* 8vo, cloth. *net*, \$2.00

— **W. S., Prof.** *Elements of the Differential and Integral Calculus. Sixth Edition, revised.* 8vo, cloth, illustrated. *net*, \$2.25

— *Descriptive Geometry, with Numerous Problems and Practical Applications.* Comprising an 8vo volume of 76 pages of text and a 4to atlas of 31 plates. 2 vols., cloth. . . . *net*, \$3.50

HALSEY, F. A. Slide-valve Gears. An Explanation of the Action and Construction of Plain and Cut-off Slide Valves. Illustrated. Seventh Edition. 12mo, cloth \$1.50

— **The Use of the Slide Rule. With illustrations and folding plates. Second Edition. 16mo, boards. (Van Nostrand's Science Series, No. 114.) 50**

— **The Locomotive Link Motion, with Diagrams and Tables. 8vo, cloth, illustrated \$1.00**

— **Worm and Spiral Gearing. Revised and Enlarged Edition. 16mo, cloth (Van Nostrand's Science Series, No. 116.) Illustrated 50**

— **The Metric Fallacy, and "The Metric Failure in the Textile Industry," by Samuel S. Dale. 8vo, cloth, illustrated \$1.00**

HAMILTON, W. G. Useful Information for Railway Men. Tenth Edition, revised and enlarged. 562 pages, pocket form. Morocco, gilt \$2.00

HAMMER, W. J. Radium, and Other Radio-active Substances; Polonium, Actinium and Thorium. With a consideration of Phosphorescent and Fluorescent Substances, the Properties and Applications of Selenium, and the treatment of disease by the Ultra-Violet Light. Second Edition. With engravings and photographic plates. 8vo, cloth, illustrated, 72 pp. . . \$1.00

HANCOCK, H. Text-book of Mechanics and Hydrostatics, with over 500 diagrams. 8vo, cloth net, \$1.50

HARDY, E. Elementary Principles of Graphic Statics. Containing 192 diagrams. 8vo, cloth, illustrated \$1.50

HARRISON, W. B. The Mechanics' Tool-book. With Practical Rules and Suggestions for use of Machinists, Iron-workers and others. With 44 engravings. 12mo, cloth . . . \$1.50

HART, J. W. External Plumbing Work. A Treatise on Lead Work for Roofs. With numerous figures and diagrams. 8vo, cloth, illustrated net, \$3.00

— **Hints to Plumbers on Joint Wiping, Pipe Bending, and Lead Burning. Containing 184 figures and diagrams. 8vo, cloth, illustrated net, \$3.00**

HART, J. W. *Principles of Hot-water Supply.* With numerous illustrations. 8vo, cloth. *net*, \$3.00

— **Sanitary Plumbing and Drainage.** With numerous diagrams and figures. 8vo, cloth, illustrated *net*, \$3.00

HASKINS, C. H. *The Galvanometer and its Uses.* A Manual for Electricians and Students. *Fourth Edition.* 12mo. cloth. \$1.50

HAUFF, W. A. *American Multiplier: Multiplications and Divisions of the largest numbers rapidly performed.* With index giving the results instantly of all numbers to $1000 \times 1000 = 1,000,000$; also tables of circumferences and areas of circles. Cloth, $6\frac{1}{2} \times 15\frac{1}{2}$ \$5.00

HAUSBRAND, E. *Drying by Means of Air and Steam.* With explanations, formulas, and tables, for use in practice. Translated from the German by A. C. Wright, M.A. 12mo, cloth, illustrated. *net*, \$2.00

— **Evaporating, Condensing and Cooling Apparatus:** Explanations, Formulæ, and Tables for Use in Practice. Translated from the Second Revised German Edition by A. C. Wright, M.A. With numerous figures, tables and diagrams. 8vo, cloth, illustrated, 400 pages. *net*, \$5.00

HAUSNER, A. *Manufacture of Preserved Foods and Sweetmeats.* A Handbook of all the Processes for the Preservation of Flesh, Fruit, and Vegetables, and for the Preparation of Dried Fruit, Dried Vegetables, Marmalades, Fruit-syrups, and Fermented Beverages, and of all kinds of Candies, Candied Fruit Sweetmeats, Rocks, Drops, Dragees, Pralines, etc. Translated from the Third Enlarged German Edition, by Arthur Morris and Herbert Robson, B.Sc. 8vo, cloth, illustrated. *net*, \$3.00

HAWKE, W. H. *The Premier Cipher Telegraphic Code,* containing 100,000 Words and Phrases. The most complete and most useful general code yet published. 4to, cloth. \$5.00

— **100,000 Words Supplement to the Premier Code.** All the words are selected from the official vocabulary. Oblong quarto, cloth. \$5.00

HAWKESWORTH, J. *Graphical Handbook for Reinforced Concrete Design.* A series of plates, showing graphically, by means of plotted curves, the required design for slabs, beams, and columns under various conditions of external loading, together with practical examples showing the method of using each plate. 8vo, cloth. *In Press.*

- HAWKINS, C. C., and WALLIS, F.** *The Dynamo: its Theory, Design, and Manufacture.* 190 illustrations. 12mo, cloth.....*net*, \$3.00
- HAY, A.** *Alternating Currents; Their Theory, Generation, and Transformation.* 8vo, cloth, illustrated.....*net*, \$2.50
- *Principles of Alternate-current Working.* 12mo, cloth, illustrated..... \$2.00
- HEAP, D. P., Major, U.S.A.** *Electrical Appliances of the Present Day.* Report of the Paris Electrical Exposition of 1881. 250 illustrations. 8vo, cloth..... \$2.00
- HEAVISIDE, O.** *Electromagnetic Theory.* 8vo, cloth, two volumes.....each, \$5.00
- HECK, R. C. H.** *Steam-Engine and Other Steam Motors.* A text-book for engineering colleges and a treatise for engineers. Vol. I. *The Thermodynamics and the Mechanics of the Engine.* With numerous figures, diagrams, and tables. 8vo, cloth, illustrated.....*net*, \$3.50
Vol. II. *Form, Construction, and Working of the Engine: The Steam Turbine.* 8vo, cloth, illustrated.....*net*, \$3.50
- HEDGES, K.** *Modern Lightning Conductors.* An Illustrated Supplement to the Report of the Lightning Research Committee of 1905, with Notes as to Methods of Protection and Specifications. With figures, half-tones, and folding tables. 8vo, cloth, illustrated.....*net*, \$3.00
- HEERMANN, P.** *Dyers' Materials.* An Introduction to the Examination, Valuation, and Application of the most important substances used in Dyeing, Printing, Bleaching and Finishing. Translated by Arthur C. Wright, M.A. 12mo, cloth, illustrated.....*net*, \$2.50
- HENRICI, O.** *Skeleton Structures, Applied to the Building of Steel and Iron Bridges.* 8vo, cloth, illustrated..... \$1.50
- HERMANN, F.** *Painting on Glass and Porcelain and Enamel Painting.* On the basis of Personal Practical Experience of the Condition of the Art up to date. Translated by Charles Salter. *Second greatly enlarged edition.* 8vo, cloth, illustrated,
net, \$3.50
- HERRMANN, G.** *The Graphical Statics of Mechanism.* A Guide for the Use of Machinists, Architects and Engineers; and also a Text-book for Technical Schools. Translated and annotated by A. P. Smith, M.E. *Fourth Edition.* 12mo, cloth, 7 folding plates..... \$2.00

- HERZFELD, J., Dr.** *The Technical Testing of Yarns and Textile Fabrics*, with reference to official specifications. Translated by Chas. Salter. With 69 illustrations. 8vo, cloth *net*, \$3.50
- HEWSON, W.** *Principles and Practice of Embanking Lands from River Floods*, as applied to the Levees of the Mississippi. 8vo, cloth. \$2.00
- HILL, J. W.** *The Purification of Public Water Supplies*. Illustrated with valuable tables, diagrams, and cuts. 8vo, cloth. \$3.00
- HIROI, I.** *Statically-Indeterminate Stresses in Frames Commonly Used for Bridges*. With figures, diagrams, and examples. 12mo, cloth, illustrated. *net*, \$2.00
- HOBBS, W. R. P.** *The Arithmetic of Electrical Measurements*, with numerous examples, fully worked. Revised by Richard Wormell, M.A. *Ninth Edition*. 12mo, cloth. 50
- HOFF, J. N.** *Paint and Varnish Facts and Formulas*. A hand-book for the maker, dealer, and user of paints and varnishes. Containing over 600 recipes. 8vo, cloth. *net*, \$3.00
- HOFF, WM. B., Com., U.S.N.** *The Avoidance of Collisions at Sea*. 18mo, morocco. 75
- HOLLEY, A. L.** *Railway Practice*. American and European Railway Practice in the Economical Generation of Steam, including the Materials and Construction of Coal-burning Boilers, Combustion, the Variable Blast, Vaporization, Circulation, Superheating, Supplying and Heating Feed Water, etc., and the Adaptation of Wood and Coke-burning Engines to Coal-burning; and in Permanent Way, including Road-bed, Sleepers, Rails, Joint Fastenings, Street Railways, etc. With 77 lithographed plates. Folio, cloth. \$12.00
- HOLMES, A. B.** *The Electric Light Popularly Explained*. *Fifth Edition*. Illustrated. 12mo, paper. 40
- HOPKINS, N. M.** *Experimental Electrochemistry: Theoretically and Practically Treated*. With 132 figures and diagrams. 8vo, cloth, illustrated. *net*, \$3.00
- **Model Engines and Small Boats**. *New Methods of Engine and Boiler Making*, with a chapter on Elementary Ship Design and Construction. 12mo, cloth. \$1.25

HORNER, J. *Engineers' Turning, in Principle and Practice.* A Handbook for Working Engineers, Technical Students, and Amateurs. With 488 figures and diagrams. 8vo, cloth, illustrated. *net*, \$3.50

HOUSTON, E. J., and KENNELLY, A. E. *Algebra Made Easy.* Being a clear explanation of the Mathematical Formulæ found in Prof. Thompson's "Dynamo-electric Machinery and Polyphase Electric Currents." With figures and examples. 8vo, cloth, illustrated. 75

— *The Interpretation of Mathematical Formulæ.* With figures and examples. 8vo, cloth, illustrated. \$1.25

HOWARD, C. R. *Earthwork Mensuration on the Basis of the Prismoidal Formulæ.* Containing Simple and Labor-saving Methods of obtaining Prismoidal Contents directly from End Areas. Illustrated by Examples and accompanied by Plain Rules for Practical Use. Illustrated. 8vo, cloth. \$1.50

HOWORTH, J. *Art of Repairing and Riveting Glass, China and Earthenware.* *Second Edition.* 8vo, pamphlet, illustrated. *net*, \$0.50

HUBBARD, E. *The Utilization of Wood-waste.* A Complete Account of the Most Advantageous Methods of Working Up Wood Refuse, especially Sawdust, Exhausted Dye Woods and Tan as Fuel, as a Source of Chemical Products for Artificial Wood Compositions, Explosives, Manures, and many other Technical Purposes. Translated from the German of the *second revised and enlarged edition.* 8vo, cloth, illustrated, 192 pages. . *net*, \$2.50

HUMBER, W., C.E. *A Handy Book for the Calculation of Strains in Girders, and Similar Structures, and their Strength; consisting of Formulæ and Corresponding Diagrams, with numerous details for practical application, etc.* *Fourth Edition.* 12mo, cloth. \$2.50

HUMPHREYS, A. C. (Stevens Institute). *Lecture Notes on some of the Business Features of Engineering Practice.* 8vo, cloth, with supplement. *net*, \$1.25

HURST, G. H., F.C.S. *Color.* A Handbook of the Theory of Color. A practical work for the Artist, Art Student, Painter, Dyer and Calico Printer, and Others. Illustrated with 10 colored plates and 72 illustrations. 8vo, cloth. *net*, \$2.50

— *Dictionary of Chemicals and Raw Products Used in the Manufacture of Paints, Colors, Varnishes and Allied Preparations.* 8vo, cloth. *net*, \$3.00

- HURST, G.H., F.C.S.** *Lubricating Oils, Fats and Greases: Their Origin, Preparation, Properties, Uses and Analysis.* 313 pages, with 65 illustrations. 8vo, cloth. *net*, \$3.00
- **Soaps.** *A Practical Manual of the Manufacture of Domestic, Toilet and other Soaps.* Illustrated with 66 engravings. 8vo, cloth. *net*, \$5.00
- **Textile Soaps and Oils: A Handbook on the Preparation, Properties, and Analysis of the Soaps and Oils Used in Textile Manufacturing, Dyeing and Printing.** With tables and illustrations. 8vo, cloth. *net*, \$2.50
- HUTCHINSON, R. W., Jr.** *Long Distance Electric Power Transmission: being a Treatise on the Hydro-electric Generation of Energy; its Transformation, Transmission, and Distribution.* 12mo, cloth, illustrated. *In Press.*
- **and IHLENG, M. C.** *Electricity in Mining; being a Theoretical and Practical Treatise on the Construction, Operation, and Maintenance of Electrical Mining Machinery.* 12mo, cloth, illustrated. *In Press.*
- **W. B.** *Patents and How to Make Money out of Them.* 12mo, cloth. \$1.25
- HUTTON, W. S.** *Steam-boiler Construction. A Practical Handbook for Engineers, Boiler-makers and Steam-users.* Containing a large collection of rules and data relating to recent practice in the design, construction and working of all kinds of stationary, locomotive and marine steam-boilers. With upwards of 540 illustrations. *Fourth Edition, carefully revised and much enlarged.* 8vo, cloth. \$6.00
- **Practical Engineer's Handbook, comprising a Treatise on Modern Engines and Boilers, Marine, Locomotive and Stationary.** *Fourth Edition, carefully revised, with additions.* With upwards of 570 illustrations. 8vo, cloth. \$7.00
- **The Works' Manager's Handbook of Modern Rules, Tables and Data for Civil and Mechanical Engineers, Millwrights and Boiler-makers, etc., etc.** With upwards of 150 illustrations. *Fifth Edition, carefully revised, with additions.* 8vo, cloth. \$6.00
- INGLE, H.** *Manual of Agricultural Chemistry.* 8vo, cloth, illustrated, 388 pages. *net*, \$3.00

INNES, C. H. *Problems in Machine Design.* For the use of Students, Draughtsmen and others. *Second Edition*, 12mo, cloth. *net*, \$2.00

— **Centrifugal Pumps, Turbines and Water Motors.** Including the Theory and Practice of Hydraulics. *Fourth and enlarged edition*. 12mo, cloth. *net*, \$2.00

ISHERWOOD, B. F. *Engineering Precedents for Steam Machinery.* Arranged in the most practical and useful manner for Engineers. With illustrations. Two volumes in one. 8vo, cloth. \$2.50

JAMIESON, A., C.E. *A Text-book on Steam and Steam-engines.* Specially arranged for the use of Science and Art, City and Guilds of London Institute, and other Engineering Students. *Thirteenth Edition.* Illustrated. 12mo, cloth. \$3.00

— **Elementary Manual on Steam and the Steam-engine.** Specially arranged for the use of First-year Science and Art, City and Guilds of London Institute, and other Elementary Engineering Students. *Third Edition.* 12mo, cloth. \$1.50

JANNETTAZ, E. *A Guide to the Determination of Rocks:* being an Introduction to Lithology. Translated from the French by G. W. Plympton, Professor of Physical Science at Brooklyn Polytechnic Institute. 12mo, cloth. \$1.50

JEHL, F., Mem. A.I.E.E. *The Manufacture of Carbons* for Electric Lighting and Other Purposes. A Practical Handbook, giving a complete description of the art of making carbons, electros, etc. The various gas generators and furnaces used in carbonizing, with a plan for a model factory. Illustrated with numerous diagrams, tables, and folding plates. 8vo, cloth, illustrated. *net*, \$4.00

JENNISON, F. H. *The Manufacture of Lake Pigments* from Artificial Colors. A useful handbook for color manufacturers, dyers, color chemists, paint manufacturers, drysalters, wallpaper-makers, enamel and surface-paper makers. With 15 plates illustrating the various methods and errors that arise in the different processes of production. 8vo, cloth. *net*, \$3.00

JEPSON, G. *Cams, and the Principles of their Construction.* With figures, half-tones, full-page and folding plates. 8vo, cloth, illustrated. *net*, \$1.50

JOCKIN, WM. *Arithmetic of the Gold and Silversmith.* Prepared for the use of Jewelers, Founders, Merchants, etc., especially for those engaged in the conversion and alloying of gold or other metals, the mixing of various substances, etc. With numerous examples. 12mo, cloth. \$1.25

- JOHNSON, W. McA.** "The Metallurgy of Nickel." *In Press.*
- JOHNSTON, J. F. W., Prof., and CAMERON, Sir Chas.**
Elements of Agricultural Chemistry and Geology. *Seventeenth Edition.* 12mo; cloth. \$2.60
- JONES, H. C.** Outlines of Electrochemistry. With tables and diagrams. 4to, cloth, illustrated. \$1.50
- Electrical Nature of Matter and Radioactivity. 12mo, cloth. net, \$2.00
- JONES, M. W.** The Testing and Valuation of Raw Materials used in Paint and Color Manufacture. 12mo, cloth, net, \$2.00
- JOYNSON, F. H.** The Metals Used in Construction. Iron, Steel, Bessemer Metal, etc. Illustrated. 12mo, cloth. 75
- Designing and Construction of Machine Gearing. Illustrated. 8vo, cloth. \$2.00
- JÜPTNER, H. F. V.** Siderology: The Science of Iron. (The Constitution of Iron Alloys and Iron.) Translated from the German. 8vo, cloth, 345 pages, illustrated. net, \$5.00
- KANSAS CITY BRIDGE, THE.** With an Account of the Regimen of the Missouri River and a Description of the Methods used for Founding in that River, by O. Chanute, Chief Engineer, and George Morison, Assistant Engineer. Illustrated with 5 lithographic views and 12 plates of plans. 4to, cloth. \$6.00
- KAPP, G., C.E.** Electric Transmission of Energy and its Transformation, Subdivision and Distribution. A practical handbook. *Fourth Edition, revised.* 12mo, cloth. \$3.50
- Dynamos, Motors, Alternators and Rotary Converters. Translated from the *third German edition*, by Harold H. Simmons, A.M.I.E.E. With numerous diagrams and figures. 8vo, cloth, 507 pages. \$4.00
- KEIM, A. W.** Prevention of Dampness in Buildings. With Remarks on the Causes, Nature and Effects of Saline Efflorescences and Dry Rot. For Architects, Builders, Overseers, Plasterers, Painters and House Owners. Translated from the *second revised, German edition.* With colored plates and diagrams. 8vo, cloth, illustrated, 115 pages. net, \$2.00
- KELSEY, W. R.** Continuous-current Dynamos and Motors, and their Control: being a series of articles reprinted from *The Practical Engineer*, and completed by W. R. Kelsey. With many figures and diagrams. 8vo, cloth, illustrated. . . \$2.50

KEMP, J. F., A.B., E.M. (Columbia Univ.). A Handbook of Rocks. For use without the microscope. With a glossary of the names of rocks and of other lithological terms. *Third Edition, revised.* 8vo, cloth, illustrated..... \$1.50

KEMPE, H. R. The Electrical Engineer's Pocket-book of Modern Rules, Formulæ, Tables and Data. Illustrated. 32mo, morocco, gilt. \$1.75

KENNEDY, R. Modern Engines and Power Generators. A Practical Work on Prime Movers and the Transmission of Power: Steam, Electric, Water, and Hot-air. With tables, figures, and full-page engravings. 6 vols. 8vo, cloth, illustrated. \$15.00

Single volumes, each. \$3.00

— **Electrical Installations of Electric Light, Power, Traction, and Industrial Electrical Machinery.** With numerous diagrams and engravings.

— **Vol. I. The Electrical Circuit, Measurement, Elements of Motors, Dynamos, Electrolysis.** 8vo, cloth, illus.. \$3.50

— **Vol. II. Instruments, Transformers, Installation Wiring, Switches and Switchboards.** 8vo, cloth, illustrated.... \$3.50

— **Vol. III. Production of Electrical Energy, Prime Movers, Generators and Motors.** 8vo, cloth, illustrated... \$3.50

— **Vol. IV. Mechanical Gearing; Complete Electric Installations; Electrolytic, Mining and Heating Apparatus; Electric Traction; Special Applications of Electric Motors.** 8vo, cloth, illustrated..... \$3.50

— **Vol. V. Apparatus and Machinery used in Telegraphs, Telephones, Signals, Wireless Telegraph, X-Rays, and Medical Science.** 8vo, cloth, illustrated. \$3.50
Complete sets of the five volumes..... \$15.00

KENNELLY, A. E. Theoretical Elements of Electrodynamical Machinery. 8vo, cloth..... \$1.50

KINGDON, J. A. Applied Magnetism. An Introduction to the Design of Electromagnetic Apparatus. 8vo, cloth.. \$3.00

KINZBRUNNER, C. *Alternate Current Windings; Their Theory and Construction.* A Handbook for Students, Designers, and all Practical Men. 8vo, cloth, illustrated.....net, \$1.50

— **Continuous Current Armatures; Their Winding and Construction.** A Handbook for Students, Designers, and all Practical Men. 8vo, cloth, illustrated.....net, \$1.50

KIRKALDY, W. G. *Illustrations of David Kirkaldy's System of Mechanical Testing, as Originated and Carried on by him during a Quarter of a Century.* Comprising a Large Selection of Tabulated Results, showing the Strength and other Properties of Materials used in Construction, with Explanatory Text and Historical Sketch. Numerous engravings and 25 lithographed plates. 4to, cloth.....\$10.00

KIRKBRIDE, J. *Engraving for Illustration: Historical and Practical Notes, with illustrations and 2 plates by ink photo process.* 8vo, cloth, illustrated.....net, \$1.50

KIRKWOOD, J. P. *Report on the Filtration of River Waters for the Supply of Cities, as practised in Europe, made to the Board of Water Commissioners of the City of St. Louis.* Illustrated by 30 double-page engravings. 4to, cloth....\$7.50

KLEIN, J. F. *Design of a High-speed Steam-engine.* With notes, diagrams, formulas and tables. *Second Edition, revised and enlarged.* 8vo, cloth, illustrated.....net, \$5.00

KLEINHANS, F. B. *Boiler Construction.* A Practical explanation of the best modern methods of Boiler Construction, from the laying out of sheets to the completed Boiler. With diagrams and full-page engravings. 8vo, cloth, illustrated..\$3.00

KNIGHT, A. M., Lieut.-Com. U.S.N. *Modern Seamanship.* Illustrated with 136 full-page plates and diagrams. 8vo, cloth, illustrated. *Second Edition, revised.*.....net, \$6.00
Half morocco.....\$7.50

KNOTT, C. G., and MACKAY, J. S. *Practical Mathematics.* With numerous examples, figures and diagrams. *New Edition.* 8vo, cloth, illustrated.....\$2.00

KOLLER, T. *The Utilization of Waste Products.* A Treatise on the Rational Utilization, Recovery and Treatment of Waste Products of all kinds. Translated from the German *second revised edition.* With numerous diagrams. 8vo, cloth, illustrated.....net, \$3.50

KOLLER, T. Cosmetics. A Handbook of the Manufacture,
Employment and Testing of all Cosmetic Materials and Cosmetic
Specialties. Translated from the German by Chas. Salter. 8vo.
cloth. net, \$2.50

KRAUCH, C., Dr. Testing of Chemical Reagents for
Purity. Authorized translation of the *Third Edition*, by J. A.
Williamson and L. W. Dupre. With additions and emendations
by the author. 8vo, cloth. net, \$4.50

LAMBERT, T. Lead, and its Compounds. With tables,
diagrams and folding plates. 8vo, cloth. net, \$3.50

— **Bone Products and Manures. An Account of**
the most recent improvements in the manufacture of Fat, Glue,
Animal Charcoal, Size, Gelatine and Manures. With plans and
diagrams. 8vo, cloth, illustrated. net, \$3.00

LAMBORN, L. L. Cottonseed Products: A Manual of the
Treatment of Cottonseed for its Products and Their Utilization
in the Arts. With Tables, figures, full-page plates, and a large
folding map. 8vo, cloth, illustrated. net, \$3.00

— **Modern Soaps, Candles, and Glycerin. A practical**
manual of modern methods of utilization of Fats and Oils in the
manufacture of Soaps and Candles, and the recovery of Glycerin.
8vo, cloth, illustrated. net, \$7.50

LAMPRECHT, R. Recovery Work after Pit Fires. A
description of the principal methods pursued, especially in fiery
mines, and of the various appliances employed, such as respira-
tory and rescue apparatus, dams, etc. With folding plates and
diagrams. Translated from the German by Charles Salter. 8vo,
cloth, illustrated. net, \$4.00

LARRABEE, C. S. Cipher and Secret Letter and Tele-
graphic Code, with Hog's Improvements. The most perfect
Secret Code ever invented or discovered. Impossible to read
without the key. 18mo, cloth. 60

LASSAR-COHN, Dr. An Introduction to Modern Scien-
tific Chemistry, in the form of popular lectures suited to University
Extension Students and general readers. Translated from the
author's corrected proofs for the *second German edition*, by
M. M. Pattison Muir, M.A. 12mo, cloth, illustrated. \$2.00

LATTA, M. N. Gas Engineering Practice. With figures, diagrams and tables. 8vo, cloth, illustrated..... *In Press.*

LEASK, A. R. Breakdowns at Sea and How to Repair Them. With 89 illustrations. *Second Edition.* 8vo, cloth. \$2.00

— Triple and Quadruple Expansion Engines and Boilers and their Management. With 59 illustrations. *Third Edition, revised.* 12mo, cloth..... \$2.00

— Refrigerating Machinery: Its Principles and Management. With 64 illustrations. 12mo, cloth..... \$2.00

LECKY, S. T. S. "Wrinkles" in Practical Navigation. With 130 illustrations. 8vo, cloth. *Fourteenth Edition, revised and enlarged.*..... \$8.00

LEFÈVRE, L. Architectural Pottery: Bricks, Tiles, Pipes, Enameled Terra-Cottas, Ordinary and Incrusted Quarries, Stoneware Mosaics, Faiences and Architectural Stoneware. With tables, plates and 950 cuts and illustrations. With a preface by M. J.-C. Formigé. Translated from the French, by K. H. Bird, M.A., and W. Moore Binns. 4to, cloth, illustrated..... *net*, \$7.50

LEHNER, S. Ink Manufacture: including Writing, Copying, Lithographic, Marking, Stamping and Laundry Inks. Translated from the *fifth German edition*, by Arthur Morris and Herbert Robson, B.Sc. 8vo, cloth, illustrated..... *net*, \$2.50

LEMSTROM, Dr. Electricity in Agriculture and Horticulture. Illustrated..... *net*, \$1.50

LEVY, C. L. Electric-light Primer. A simple and comprehensive digest of all the most important facts connected with the running of the dynamo, and electric lights, with precautions for safety. For the use of persons whose duty it is to look after the plant. 8vo, paper..... .50

LIVERMORE, V. P., and WILLIAMS, J. How to Become a Competent Motorman. Being a Practical Treatise on the Proper Method of Operating a Street Railway Motor Car; also giving details how to overcome certain defects. 16mo, cloth, illustrated, 132 pages..... \$1.00

- LOBBEN, P., M.E.** *Machinists' and Draftsmen's Handbook*, containing Tables, Rules, and Formulas, with numerous examples, explaining the principles of mathematics and mechanics, as applied to the mechanical trades. Intended as a reference book for all interested in Mechanical work. Illustrated with many cuts and diagrams. 8vo, cloth. \$2.50
- LOCKE, A. G. and C. G.** *A Practical Treatise on the Manufacture of Sulphuric Acid*. With 77 constructive plates, drawn to scale measurements, and other illustrations. Royal 8vo, cloth. \$10.00
- LOCKERT, L.** *Petroleum Motor-cars*. 12mo, cloth, \$1.50
- LOCKWOOD, T. D.** *Electricity, Magnetism, and Electro-telegraphy*. A Practical Guide for Students, Operators, and Inspectors. 8vo, cloth. *Third Edition*. \$2.50
- *Electrical Measurement and the Galvanometer: its Construction and Uses*. *Second Edition*. 32 illustrations. 12mo, cloth. \$1.50
- LODGE, O. J.** *Elementary Mechanics, including Hydrostatics and Pneumatics*. *Revised Edition*. 12mo, cloth . . . \$1.50
- *Signalling Across Space, Without Wires: being a description of the work of Hertz and his successors*. With numerous diagrams and half-tone cuts, and additional remarks concerning the application to Telegraphy and later developments. *Third Edition*. 8vo, cloth, illustrated. *net*, \$2.00
- LORD, R. T.** *Decorative and Fancy Fabrics*. A Valuable Book with designs and illustrations for manufacturers and designers of Carpets, Damask, Dress and all Textile Fabrics. 8vo, cloth, illustrated. *net*, \$3.50
- LORING, A. E.** *A Handbook of the Electro-magnetic Telegraph*. 16mo, cloth, boards. *New and enlarged edition*. 50
- LUCE, S. B. (Com., U. S. N.).** *Text-book of Seamanship*. The Equipping and Handling of Vessels under Sail or Steam. For the use of the U. S. Naval Academy. *Revised and enlarged edition*, by Lieut. Wm. S. Benson. 8vo, cloth, illustrated. \$10.00
- LUCKE, C. E.** *Gas Engine Design*. With figures and diagrams. *Second Edition, revised*. 8vo, cloth, illustrated. *net*, \$3.00
- *Power, Cost and Plant Designs and Construction*.
In Press.

- LUCKE, C. E.** **Power Plant Papers. Form I. The Steam Power Plant.** Pamphlet (8×13)... *net*, \$1.50
- LUNGE, G., Ph.D.** **Coal-tar and Ammonia: being the third and enlarged edition of "A Treatise on the Distillation of Coal-tar and Ammoniacal Liquor,"** with numerous tables, figures and diagrams. Thick 8vo, cloth, illustrated... *net*, \$15.00
- **A Theoretical and Practical Treatise on the Manufacture of Sulphuric Acid and Alkali with the Collateral Branches.**
- **Vol. I. Sulphuric Acid. In two parts, not sold separately.** *Second Edition, revised and enlarged.* 342 illus. 8vo, cloth... \$15.00
- **Vol. II. Salt Cake, Hydrochloric Acid and Leblanc Soda.** *Second Edition, revised and enlarged.* 8vo, cloth... \$15.00
- **Vol. III. Ammonia Soda, and various other processes of Alkali-making, and the preparation of Alkalis, Chlorine and Chlorates, by Electrolysis.** 8vo, cloth. *New Edition, 1896.* \$15.00
- **and HURTER, F.** **The Alkali Maker's Handbook.** Tables and Analytical Methods for Manufacturers of Sulphuric Acid, Nitric Acid, Soda, Potash and Ammonia. *Second Edition.* 12mo, cloth... \$3.00
- LUPTON, A., PARR, G. D. A., and PERKIN, H.** **Electricity as Applied to Mining.** With tables, diagrams and folding plates. *Second Edition, revised and enlarged.* 8vo, cloth, illustrated... *net*, \$4.50
- LUQUER, L. M., Ph.D. (Columbia Univ.).** **Minerals in Rock Sections.** The Practical Method of Identifying Minerals in Rock Sections with the Microscope. Especially arranged for Students in Technical and Scientific Schools. *Revised Edition.* 8vo, cloth, illustrated... *net*, \$1.50
- MACKIE, JOHN.** **How to Make a Woolen Mill Pay.** 8vo, cloth... *net*, \$2.00
- MACKROW, C.** **The Naval Architect's and Ship-builder's Pocket-book of Formulæ, Rules, and Tables; and Engineers' and Surveyors' Handy Book of Reference.** *Eighth Edition, revised and enlarged.* 16mo, limp leather, illustrated... \$5.00
- MAGUIRE, E., Capt., U.S.A.** **The Attack and Defence of Coast Fortifications** With maps and numerous illustrations. 8vo, cloth... \$2.50

MAGUIRE, WM. R. Domestic Sanitary Drainage and Plumbing Lectures on Practical Sanitation. 332 illustrations. 8vo. \$4.00

MAILLOUX, C. O. Electro-traction Machinery. 8vo, cloth, illustrated. *In Press.*

MARKS, E. C. R. Notes on the Construction of Cranes and Lifting Machinery. With numerous diagrams and figures. *New and enlarged edition.* 12mo, cloth. *net*, \$1.50

— **Notes on the Construction and Working of Pumps.** With figures, diagrams and engravings. 12mo, cloth, illustrated. *net*, \$1.50

— **G. C. Hydraulic Power Engineering.** A Practical Manual on the Concentration and Transmission of Power by Hydraulic Machinery. With over 200 diagrams and tables 8vo, cloth, illustrated. \$3.50

MARSH, C. F. Reinforced Concrete. With full-page and folding plates, and 512 figures and diagrams. 4to, cloth, illustrated. *net*, \$7.00

MAVER, W. American Telegraphy: Systems, Apparatus, Operation. 450 illustrations. 8vo, cloth. \$5.00

MAYER, A. M., Prof. Lecture Notes on Physics. 8vo, cloth. \$2.00

McCULLOCH, R. S., Prof. Elementary Treatise on the Mechanical Theory of Heat, and its application to Air and Steam-engines. 8vo, cloth. \$3.50

McINTOSH, J. G. Technology of Sugar. A Practical Treatise on the Manufacture of Sugar from the Sugar-cane and Sugar-beet. With diagrams and tables. 8vo, cloth, illustrated. *net*, \$4.50

— **Manufacture of Varnishes and Kindred Industries.** Based on and including the "Drying Oils and Varnishes," of Ach. Livache. Volume I. Oil Crushing, Refining and Boiling, Manufacture of Linoleum, Printing and Lithographic Inks, and India-rubber Substitutes. *Second greatly enlarged English Edition.* 8vo, cloth, illustrated. *net*, \$3.50
 - (To be complete in three volumes.)

McNEILL, B. *McNeill's Code. Arranged to meet the requirements of Mining, Metallurgical and Civil Engineers, Directors of Mining, Smelting and other Companies, Bankers, Stock and Share Brokers, Solicitors, Accountants, Financiers and General Merchants. Safety and Secrecy.* 8vo, cloth. . . . \$6.00

McPHERSON, J. A., A. M. Inst. C. E. *Waterworks Distribution.* A practical guide to the laying out of systems of distributing mains for the supply of water to cities and towns With tables, folding plates and numerous full-page diagrams 8vo, cloth, illustrated. \$2.50

MERCK, E. *Chemical Reagents: Their Purity and Tests.*
In Press.

MERRITT, WM. H. *Field Testing for Gold and Silver.* A Practical Manual for Prospectors and Miners. With numerous half-tone cuts, figures and tables. 16mo, limp leather, illustrated. \$1.50

METAL TURNING. By a Foreman Pattern-maker. Illustrated with 81 engravings. 12mo, cloth. \$1.50

MICHELL, S. *Mine Drainage: being a Complete Practical Treatise on Direct-acting Underground Steam Pumping Machinery.* Containing many folding plates, diagrams and tables. *Second Edition, rewritten and enlarged.* Thick 8vo, cloth, illustrated. \$10.00

MIERZINSKI, S., Dr. *Waterproofing of Fabrics.* Translated from the German by Arthur Morris and Herbert Robson. With diagrams and figures. 8vo, cloth, illustrated. . . . *net*, \$2.50

MILLER, E. H. (Columbia Univ.). *Quantitative Analysis for Mining Engineers.* 8vo, cloth. *net*, \$1.50

MINIFIE, W. *Mechanical Drawing. A Text-book of Geometrical Drawing for the use of Mechanics and Schools, in which the Definitions and Rules of Geometry are familiarly explained; the Practical Problems are arranged from the most simple to the more complex, and in their description technicalities are avoided as much as possible. With illustrations for drawing Plans, Sections, and Elevations of Railways and Machinery; an Introduction to Isometrical Drawing, and an Essay on Linear Perspective and Shadows. Illustrated with over 200 diagrams engraved on steel. Tenth Thousand, revised. With an Appendix on the Theory and Application of Colors.* 8vo, cloth. . \$4.00

MINIFIE, W. Geometrical Drawing. Abridged from the octavo edition, for the use of schools. Illustrated with 48 steel plates. *Ninth Edition.* 12mo, cloth..... \$2.00

MODERN METEOROLOGY. A Series of Six Lectures, delivered under the auspices of the Meteorological Society in 1870. Illustrated. 12mo, cloth..... \$1.50

MOORE, E. C. S. New Tables for the Complete Solution of Ganguillet and Kutter's Formula for the flow of liquids in open channels, pipes, sewers and conduits. In two parts. Part I, arranged for 1080 inclinations from 1 over 1 to 1 over 21,120 for fifteen different values of (*n*). Part II, for use with all other values of (*n*). With large folding diagram. 8vo, cloth, illustrated..... net, \$5.00

MOREING, C. A., and NEAL, T. New General and Mining Telegraph Code. 676 pages, alphabetically arranged. For the use of mining companies, mining engineers, stock brokers, financial agents, and trust and finance companies. *Eighth Edition.* 8vo, cloth..... \$5.00

MOSES, A. J. The Characters of Crystals. An Intro-duction to Physical Crystallography, containing 321 illustrations and diagrams. 8vo..... net, \$2.00

— and **PARSONS, C. L. Elements of Mineralogy,** Crystallography and Blowpipe Analysis from a Practical Standpoint. *Third Enlarged Edition.* 8vo, cloth, 336 illustrations, net, \$2.50

MOSS, S. A. Elements of Gas Engine Design. Reprint of a Set of Notes accompanying a Course of Lectures delivered at Cornell University in 1902. 16mo, cloth, illustrated. (Van Nostrand's Science Series)..... \$0.50

MOSS, S. A. The Lay-out of Corliss Valve Gears. (*Van Nostrand's Science Series.*) 16mo, cloth, illustrated..... \$0.50

MULLIN, J. P., M.E. Modern Moulding and Pattern-making. A Practical Treatise upon Pattern-shop and Foundry Work: embracing the Moulding of Pulleys, Spur Gears, Worm Gears, Balance-wheels, Stationary Engine and Locomotive Cylinders, Globe Valves, Tool Work, Mining Machinery, Screw Propellers, Pattern-shop Machinery, and the latest improvements in English and American Cupolas; together with a large collection of original and carefully selected Rules and Tables for every-day use in the Drawing Office, Pattern-shop and Foundry. 12mo, cloth, illustrated..... \$2.50

- MUNRO, J., C.E., and JAMIESON, A., C.E.** A Pocket-book of Electrical Rules and Tables for the use of Electricians and Engineers. *Fifteenth Edition, revised and enlarged.* With numerous diagrams. Pocket size. Leather. \$2.50
- MURPHY, J. G., M.E.** Practical Mining. A Field Manual for Mining Engineers. With Hints for Investors in Mining Properties. 16mo, cloth. \$1.00
- NAQUET, A.** Legal Chemistry. A Guide to the Detection of Poisons, Falsification of Writings, Adulteration of Alimentary and Pharmaceutical Substances, Analysis of Ashes, and Examination of Hair, Coins, Arms and Stains, as applied to Chemical Jurisprudence, for the use of Chemists, Physicians, Lawyers, Pharmacists and Experts. Translated, with additions, including a list of books and memoirs on Toxicology, etc., from the French, by J. P. Battershall, Ph.D., with a Preface by C. F. Chandler, Ph.D., M.D., LL.D. 12mo, cloth. \$2.00
- NASMITH, J.** The Student's Cotton Spinning. Third Edition, revised and enlarged. 8vo, cloth, 622 pages, 250 illustrations. \$3.00
- NEUBURGER, H., and NOALHAT, H.** Technology of Petroleum. The Oil Fields of the World: their History, Geography and Geology. Annual Production, Prospection and Development; Oil-well Drilling; Transportation of Petroleum by Land and Sea. Storage of Petroleum. With 153 illustrations and 25 plates. Translated from the French, by John Geddes McIntosh. 8vo, cloth, illustrated. net, \$10.00
- NEWALL, J. W.** Plain Practical Directions for Drawing, Sizing and Cutting Bevel-gears, showing how the Teeth may be cut in a Plain Milling Machine or Gear Cutter so as to give them a correct shape from end to end; and showing how to get out all particulars for the Workshop without making any Drawings. Including a Full Set of Tables of Reference. Folding plates. 8vo, cloth. \$1.50
- NEWLANDS, J.** The Carpenters' and Joiners' Assistant: being a Comprehensive Treatise on the Selection, Preparation and Strength of Materials, and the Mechanical Principles of Framing, with their application in Carpentry, Joinery and Hand-railing; also, a Complete Treatise on Sines; and an Illustrated Glossary of Terms used in Architecture and Building. Illustrated. Folio, half morocco. \$15.00

- NIPHER, F. E., A.M.** *Theory of Magnetic Measurements*, with an Appendix on the Method of Least Squares. 12mo, cloth. \$1.00
- NOLL, AUGUSTUS.** *How to Wire Buildings: A Manual of the Art of Interior Wiring.* With many illustrations. *Fourth Edition.* 8vo, cloth, illustrated. \$1.50
- NUGENT, E.** *Treatise on Optics; or, Light and Sight* Theoretically and Practically Treated, with the Application to Fine Art and Industrial Pursuits. With 103 illustrations. 12mo, cloth. \$1.50
- O'CONNOR, H.** *The Gas Engineer's Pocket-book.* Comprising Tables, Notes and Memoranda relating to the Manufacture, Distribution and Use of Coal-gas and the Construction of Gas-works. *Second Edition, revised.* 12mo, full leather, gilt edges. \$3.50
- OLSEN, J. C., Prof.** *Text-book of Quantitative Chemical Analysis* by Gravimetric, Electrolytic, Volumetric and Gasometric Methods. With Seventy-two Laboratory Exercises giving the Analysis of Pure Salts, Alloys, Minerals and Technical Products. With numerous figures and diagrams. *Second Edition, revised.* 8vo, cloth. net, \$4.00
- OSBORN, F. C.** *Tables of Moments of Inertia, and Squares of Radii of Gyration;* supplemented by others on the Ultimate and Safe Strength of Wrought-iron Columns, Safe Strength of Timber Beams, and Constants for readily obtaining the Shearing Stresses, Reactions and Bending Moments in Swing Bridges. *Fifth Edition.* 12mo, leather. net, \$3.00
- LOUDIN, M. A.** *Standard Polyphase Apparatus and Systems.* With many diagrams and figures. *Third Edition, thoroughly revised.* Fully illustrated. \$3.00
- PALAZ, A., Sc.D.** *A Treatise on Industrial Photometry,* with special application to Electric Lighting. Authorized translation from the French by George W. Patterson, Jr. *Second Edition, revised.* 8vo, cloth, illustrated. \$4.00
- PAMELY, C.** *Colliery Manager's Handbook.* A Comprehensive treatise on the Laying-out and Working of Collieries. Designed as a book of reference for colliery managers and for the use of coal-mining students preparing for first-class certificates. *Fifth Edition, revised and enlarged.* Containing over 1,000 diagrams, plans, and engravings. 8vo, cloth, illustrated. net, \$10.00

PARR, G. D. A. **Electrical Engineering Measuring Instruments**, for Commercial and Laboratory Purposes. With 370 diagrams and engravings. 8vo, cloth, illustrated.....*net*, \$3.50

PARRY, E. J., B.Sc. **The Chemistry of Essential Oils and Artificial Perfumes.** Being an attempt to group together the more important of the published facts connected with the subject; also giving an outline of the principles involved in the preparation and analysis of Essential Oils. With numerous diagrams and tables. 8vo, cloth, illustrated.....*net*, \$5.00

— **and COSTE, J. H.** **Chemistry of Pigments.** With tables and figures. 8vo, cloth.....*net*, \$4.50

PARRY, L. A., M.D. **The Risks and Dangers of Various Occupations and their Prevention.** A book that should be in the hands of manufacturers, the medical profession, sanitary inspectors, medical officers of health, managers of works, foremen and workmen. 8vo, cloth.....*net*, \$3.00

PARSHALL, H. F., and HOBART, H. M. **Armature Windings of Electric Machines.** With 140 full-page plates, 65 tables and 165 pages of descriptive letter-press. 4to, cloth. \$7.50

— **and PARRY, E.** **Electrical Equipment of Tramways.**
In Press.

PASSMORE, A. C. **Handbook of Technical Terms used in Architecture and Building, and their Allied Trades and Subjects.** 8vo, cloth.....*net*, \$3.50

PATERSON, D., F.C.S. **The Color Printing of Carpet Yarns.** A useful manual for color chemists and textile printers. With numerous illustrations. 8vo, cloth, illustrated...*net*, \$3.50

— **Color Matching on Textiles.** A Manual intended for the use of Dyers, Calico Printers, and Textile Color Chemists. Containing colored frontispiece and 9 illustrations, and 14 dyed patterns in appendix. 8vo, cloth, illustrated.....*net*, \$3.00

— **The Science of Color Mixing.** A Manual intended for the use of Dyers, Calico Printers, and Color Chemists. With figures, tables, and colored plate. 8vo, cloth, illustrated...*net*, \$3.00

PATTEN, J. **A Plan for Increasing the Humidity of the Arid Region and the Utilization of Some of the Great Rivers of the United States for Power and other Purposes.** A paper communicated to the National Irrigation Congress, Ogden, Utah. Sept. 12, 1903. 4to, pamphlet, 20 pages, with 7 maps. .. \$1.00

PATTON, H. B. **Lecture Notes on Crystallography**
Revised Edition, largely rewritten. Prepared for use of the students at the Colorado School of Mines. With blank pages for note-taking. 8vo, cloth. *net* \$1.25

PAULDING, C. P. **Practical Laws and Data on the Condensation of Steam in Covered and Bare Pipes;** to which is added a translation of Péclet's "Theory and Experiments on the Transmission of Heat Through Insulating Materials." 8vo, cloth, illustrated, 102 pages. *net*, \$2.00

— **Transmission of Heat through Cold-storage Insulation:** Formulas, Principles, and Data Relating to Insulation of Every Kind. A Manual for refrigerating engineers. With tables and diagrams. 12mo, cloth, illustrated. *net*, \$1.00

PEIRCE, B. **System of Analytic Mechanics.** 4to, cloth. \$10.00

PERRINE, F. A. C., A.M., D.Sc. **Conductors for Electrical Distribution:** their Manufacture and Materials, the Calculation of Circuits, Pole Line Construction, Underground Working and other Uses. With numerous diagrams and engravings. 8vo, cloth, illustrated, 287 pages. *net*, \$3.50

PERRY, J. **Applied Mechanics. A Treatise for the Use** of students who have time to work experimental, numerical, and graphical exercises illustrating the subject. 8vo, cloth, 650 pages. *net*, \$2.50

PHILLIPS, J. **Engineering Chemistry. A Practical** Treatise for the use of Analytical Chemists, Engineers, Iron Masters, Iron Founders, students and others. Comprising methods of Analysis and Valuation of the principal materials used in Engineering works, with numerous Analyses, Examples, and Suggestions. Illustrated. *Third Edition, revised and enlarged.* 8vo, cloth. *net*, \$4.50

— **Gold Assaying. A Practical Handbook** giving the Modus Operandi for the Accurate Assay of Auriferous Ores and Bullion, and the Chemical Tests required in the Processes of Extraction by Amalgamation, Cyanidation, and Chlorination. With an appendix of tables and statistics and numerous diagrams and engravings. 8vo, cloth, illustrated. *net*, \$2.50

PHIN, J. **Seven Follies of Science. A Popular Account** of the most famous scientific impossibilities and the attempts which have been made to solve them; to which is added a small Budget of Interesting Paradoxes, Illusions, and Marvels. With numerous illustrations. 8vo, cloth, illustrated. *net*, \$1.25

- PICKWORTH, C. N.** *The Indicator Handbook. A Practical Manual for Engineers. Part I. The Indicator: its Construction and Application.* 81 illustrations. 12mo, cloth. \$1.50
- *The Indicator Handbook. Part II. The Indicator Diagram: its Analysis and Calculation. With tables and figures.* 12mo, cloth, illustrated. \$1.50
- *Logarithms for Beginners.* 8vo, boards. \$0.50
- *The Slide Rule. A Practical Manual of Instruction for all Users of the Modern Type of Slide Rule, containing Succinct Explanation of the Principle of Slide-rule Computation, together with Numerous Rules and Practical Illustrations, exhibiting the Application of the Instrument to the Every-day Work of the Engineer—Civil, Mechanical and Electrical. Seventh Edition.* 12mo, flexible cloth. \$1.00
- Plane Table, The.** *Its Uses in Topographical Surveying.* From the Papers of the United States Coast Survey. Illustrated. 8vo, cloth. \$2.00
 "This work gives a description of the Plane Table employed at the United States Coast Survey office, and the manner of using it."
- PLATTNER'S Manual of Qualitative and Quantitative Analysis with the Blow-pipe.** *Eighth Edition, revised.* Translated by Henry B. Cornwall, E.M., Ph.D., assisted by John H. Caswell, A.M. From the sixth German edition, by Prof. Friederich Kolbeck. With 87 woodcuts. 463 pages. 8vo, cloth. *net*, \$4.00
- PLYMPTON, GEO. W., Prof.** *The Aneroid Barometer: its Construction and Use.* Compiled from several sources. *Eighth Edition, revised and enlarged.* 16mo, boards, illustrated. \$0.50
- POCKET LOGARITHMS, to Four Places of Decimals,** including Logarithms of Numbers, and Logarithmic Sines and Tangents to Single Minutes. To which is added a Table of Natural Sines, Tangents, and Co-tangents. 16mo, boards. \$0.50
- POPE, F. L.** *Modern Practice of the Electric Telegraph.* A Technical Handbook for Electricians, Managers and Operators. *Fifteenth Edition, rewritten and enlarged, and fully illustrated.* 8vo, cloth. \$1.50
- POPPLEWELL, W. C.** *Elementary Treatise on Heat and Heat Engines.* Specially adapted for engineers and students of engineering. 12mo, cloth, illustrated. \$3.00

POPPLEWELL, W. C. **Prevention of Smoke, combined with the Economical Combustion of Fuel.** With diagrams, figures and tables. 8vo, cloth illustrated..... *net*, \$3.50

Practical Compounding of Oils, Tallow and Grease, for Lubrication, etc. By an Expert Oil Refiner. 8vo, cloth. *net*, \$3.50

Practical Iron Founding. By the Author of "Pattern Making," etc. Illustrated with over 100 engravings. *Third Edition.* 12mo, cloth..... \$1.50

PRAY, T., Jr. **Twenty Years with the Indicator: being a Practical Text-book for the Engineer or the Student, with no complex Formulæ.** Illustrated. 8vo, cloth..... \$2.50

— **Steam Tables and Engine Constant.** Compiled from Regnault, Rankine and Dixon directly, making use of the exact records. 8vo, cloth..... \$2.00

PREECE, W. H. **Electric Lamps.....** *In Press.*

— **and STUBBS, A. T.** **Manual of Telephony.** Illustrations and plates. 12mo, cloth..... \$4.50

PRELINI, C., C.E. **Earth and Rock Excavation. A Manual for Engineers, Contractors, and Engineering Students.** With tables and many diagrams and engravings. 8vo, cloth, illustrated. *net*, \$3.00

— **Retaining Walls and Dams.** 8vo, cloth, illustrated. *In Press.*

— **Tunneling. A Practical Treatise containing 149 Working Drawings and Figures.** With additions by Charles S. Hill, C.E., Associate Editor "Engineering News." 311 pages. *Second Edition, revised.* 8vo, cloth, illustrated..... \$3.00

PREMIER CODE. (See Hawke, Wm. H.)

PRESCOTT, A. B., Prof. **Organic Analysis. A Manual of the Descriptive and Analytical Chemistry of certain Carbon Compounds in Common Use; a Guide in the Qualitative and Quantitative Analysis of Organic Materials in Commercial and Pharmaceutical Assays, in the Estimation of Impurities under Authorized Standards, and in Forensic Examinations for Poisons, with Directions for Elementary Organic Analysis.** *Fifth Edition.* 8vo, cloth..... \$5.00

PRESCOTT, A. B., Prof. **Outlines of Proximate Organic Analysis**, for the Identification, Separation and Quantitative Determination of the more commonly occurring Organic Compounds. *Fourth Edition.* 12mo, cloth..... \$1.75

— **and JOHNSON, O. C.** **Qualitative Chemical Analysis.** A Guide in Qualitative Work, with Data for Analytical Operations, and Laboratory Methods in Inorganic Chemistry. *Sixth revised and enlarged Edition, entirely rewritten*, with an appendix by H. H. Willard, containing a few improved methods of analysis. 8vo, cloth.....net, \$3.50

— **and SULLIVAN, E. C. (University of Michigan).** **First Book in Qualitative Chemistry.** For Studies of Water Solution and Mass Action. *Twelfth Edition, entirely rewritten.* 12mo, cloth.....net, \$1.50

PRITCHARD, O. G. **The Manufacture of Electric-light Carbons.** Illustrated. 8vo, paper..... \$0.60

PROST, E. **Manual of Chemical Analysis as Applied to the Assay of Fuels, Ores, Metals, Alloys, Salts, and other Mineral Products.** Translated from the original by J. C. Smith. Part I, Fuels, Waters, Ores, Salts, and other mineral industrial products; Part II, Metals; Part III, Alloys. 8vo, cloth...net, \$4.50

PULLEN, W. W. F. **Application of Graphic Methods to the Design of Structures.** Specially prepared for the use of Engineers. A Treatment by Graphic Methods of the Forces and Principles necessary for consideration in the Design of Engineering Structures, Roofs, Bridges, Trusses, Framed Structures, Wells, Dams, Chimneys, and Masonry Structures. 12mo, cloth, profusely illustrated.....net, \$2.50

PULSIFER, W. H. **Notes for a History of Lead.** 8vo, cloth, gilt top..... \$4.00

PUTSCH, A. **Gas and Coal-dust Firing.** A Critical Review of the Various Appliances Patented in Germany for this Purpose since 1885. With diagrams and figures. Translated from the German by Charles Salter. 8vo, cloth, illustrated.....net, \$3.00

PYNCHON, T. R., Prof. **Introduction to Chemical Physics**, designed for the use of Academies, Colleges and High Schools. Illustrated with numerous engravings, and containing copious experiments, with directions for preparing them. *New Edition, revised and enlarged*, and illustrated by 269 wood engravings. 8vo, cloth..... \$3.00

RADFORD, C. S., Lieut. Handbook on Naval Gunnery.

Prepared by Authority of the Navy Department. For the use of U. S. Navy, U. S. Marine Corps, and U. S. Naval Reserves. Revised and enlarged, with the assistance of Stokely Morgan, Lieut. U. S. N. *Third Edition, revised and enlarged.* 12mo, flexible leather. *net*, \$2.00

RAFTER, G. W. Treatment of Septic Sewage (*Van Nostrand's Science Series, No. 118*). 16mo, cloth. \$0.50

— **Tables for Sewerage and Hydraulic Engineers.** *In Press.*

— **and BAKER, M. N. Sewage Disposal in the United States.** Illustrations and folding plates. *Third Edition.* 8vo, cloth. \$6.00

RAM, G. S. The Incandescent Lamp and its Manufacture. 8vo, cloth. *net*, \$3.00

RAMP, H. M. Foundry Practice *In Press.*

RANDALL, J. E. A Practical Treatise on the Incandescent Lamp. 16mo, cloth, illustrated. \$0.50

RANDALL, P. M. Quartz Operator's Handbook. *New Edition, revised and enlarged, fully illustrated.* 12mo, cloth, \$2.00

RANDAU, P. Enamels and Enamelling. An introduction to the preparation and application of all kinds of enamels for technical and artistic purposes. For enamel-makers, workers in gold and silver, and manufacturers of objects of art. *Third German Edition.* Translated by Charles Salter. With figures, diagrams and tables. 8vo, cloth, illustrated. *net*, \$4.00

RANKINE, W. J. M. Applied Mechanics. Comprising the Principles of Statics and Cinematics, and Theory of Structures, Mechanism, and Machines. With numerous diagrams. *Seventeenth Edition,* thoroughly revised by W. J. Millar. 8vo, cloth. \$5.00

— **Civil Engineering.** Comprising Engineering Surveys, Earthwork, Foundations, Masonry, Carpentry, Metalwork, Roads, Railways, Canals, Rivers, Water-works, Harbors, etc. With numerous tables and illustrations. *Twenty-first Edition,* thoroughly revised by W. J. Millar. 8vo, cloth. . . . \$6.50

RANKINE, W. J. M. *Machinery and Millwork.* Comprising the Geometry, Motions, Work, Strength, Construction, and Objects of Machines, etc. Illustrated with nearly 300 woodcuts. *Seventh Edition*, thoroughly revised by W. J. Millar. 8vo, cloth. \$5.00

— **The Steam-engine and Other Prime Movers.** With diagram of the Mechanical Properties of Steam. Folding plates, numerous tables and illustrations. *Fifteenth Edition*, thoroughly revised by W. J. Millar. 8vo, cloth..... \$5.00

— **Useful Rules and Tables for Engineers and Others.** With Appendix, Tables, Tests and Formulæ for the use of Electrical Engineers. Comprising Submarine Electrical Engineering, Electric Lighting and Transmission of Power. By Andrew Jamieson, C.E., F.R.S.E. *Seventh Edition*, thoroughly revised by W. J. Millar. 8vo, cloth..... \$4.00

— **and BAMBER, E. F., C.E.** *A Mechanical Text-book.* With numerous illustrations. *Fifth Edition*. 8vo, cloth.. \$3.50

RAPHAEL, F. C. *Localization of Faults in Electric Light and Power Mains*, with chapters on Insulation Testing. With figures and diagrams. *Second Edition, revised*. 8vo, cloth, illustrated..... net, \$3.00

RATEAU, A. *Experimental Researches on the Flow of Steam through Nozzles and Orifices*, to which is added a note on the Flow of Hot Water. (Extrait des Annales des Mines, January, 1902.) Authorized translation by H. Boyd Brydon. With figures, tables, and folding plates. 8vo, cloth, illustrated. net, \$1.50

RAUTENSTRAUCH, Prof. W. *Syllabus of Lectures and Notes on the Elements of Machine Design.* With blank pages for note-taking. 8vo, cloth, illustrated.....net, \$1.50

RAYMOND, E. B. *Alternating-current Engineering Practically Treated.* With numerous diagrams and figures. *Second Edition*. 12mo, cloth.....net, \$2.50

RAYNER, H. *Silk Throwing and Waste Silk Spinning.* With numerous diagrams and figures. 8vo, cloth, illustrated, net, \$2.50

RECIPES for the Color, Paint, Varnish, Oil, Soap and Drysaltery Trades. Compiled by an Analytical Chemist. 8vo, cloth..... \$3.50

RECIPES FOR FLINT GLASS MAKING. Being Leaves

from the mixing-book of several experts in the Flint Glass Trade. Containing up-to-date recipes and valuable information as to Crystal, Demi-crystal, and Colored Glass in its many varieties. It contains the recipes for cheap metal suited to pressing, blowing, etc., as well as the most costly Crystal and Ruby. British manufacturers have kept up the quality of this glass from the arrival of the Venetians to Hungry Hill, Stourbridge, up to the present time. The book also contains remarks as to the result of the metal as it left the pots by the respective metal mixers, taken from their own memoranda upon the originals. Compiled by a British Glass Master and Mixer. 12mo, cloth..... *net*, \$4.50

REED'S ENGINEERS' HANDBOOK to the Local Marine

Board Examinations for Certificates of Competency as First and Second Class Engineers. By W. H. Thorn. With the answers to the Elementary Questions. Illustrated by 358 diagrams and 37 large plates. *Seventeenth Edition, revised and enlarged.* 8vo, cloth..... \$5.00

— **Key to the Seventeenth Edition of Reed's Engineers' Handbook to the Board of Trade Examination for First and Second Class Engineers**, and containing the workings of all the questions given in the examination papers. By W. H. Thorn. 8vo, cloth..... \$3.00

REED. Useful Hints to Sea-going Engineers, and How to Repair and Avoid "Breakdowns"; also appendices containing Boiler Explosions, Useful Formulæ, etc. With 42 diagrams and 8 plates. *Third Edition, revised and enlarged.* 12mo, cloth..... \$1.50

— **Marine Boilers. A Treatise on the Causes and Prevention of their Priming, with Remarks on their General Management.** 12mo, cloth, illustrated..... \$2.00

REINHARDT, C. W. Lettering for Draftsmen, Engineers, and Students. A Practical System of Free-hand Lettering for Working Drawings. Revised and enlarged edition. Eighteenth Thousand. Oblong boards..... \$1.00

— **The Technic of Mechanical Drafting. A Practical guide to neat, correct and legible drawing, containing many illustrations, diagrams and full-page plates.** 4to, cloth, illus... \$1.00

REISER, F. Hardening and Tempering of Steel, in Theory and Practice. Translated from the German of the *third and enlarged edition*, by Arthur Morris and Herbert Robson. 8vo, cloth, 120 pages..... \$2.50

REISER, N. *Faults in the Manufacture of Woolen Goods, and their Prevention.* Translated from the *second German edition*, by Arthur Morris and Herbert Robson. 8vo, cloth, illustrated *net*, \$2.50

— *Spinning and Weaving Calculations with Special reference to Woolen Fabrics.* Translated from the German by Chas. Salter. 8vo, cloth, illustrated. *net*, \$5.00

RICE, J. M., and JOHNSON, W. W. *On a New Method of Obtaining the Differential of Functions, with especial reference to the Newtonian Conception of Rates or Velocities.* 12mo, paper..... \$0.50

RIDEAL, S., D.Sc. *Glue and Glue Testing, with figures and tables.* 8vo, cloth, illustrated..... *net*, \$4.00

RIPPER, W. *A Course of Instruction in Machine Drawing and Design for Technical Schools and Engineer Students.* With 52 plates and numerous explanatory engravings. Folio, cloth, ... *net*, \$6.00

ROBERTSON, L. S. *Water-tube Boilers. Based on a short course of Lectures delivered at University College, London.* With upward of 170 illustrations and diagrams. 8vo, cloth, illustrated. \$3.00

ROBINSON, S. W. *Practical Treatise on the Teeth of Wheels, with the theory and the use of Robinson's Odontograph. Third Edition, revised, with additions.* 16mo, cloth, illustrated. (Van Nostrand's Science Series.)..... \$0.50

ROEBLING, J. A. *Long and Short Span Railway Bridges.* Illustrated with large copper-plate engravings of plans and views. Imperial folio, cloth..... \$25.00

ROLLINS, W. *Notes on X-Light.* With 152 full-page plates. 8vo, cloth, illustrated..... *net*, \$7.50

ROSE, J., M.E. *The Pattern-makers' Assistant. Embracing Lathe Work, Branch Work, Core Work, Sweep Work and Practical Gear Constructions, the Preparation and Use of Tools, together with a large collection of useful and valuable Tables. Ninth Edition.* With 250 engravings. 8vo, cloth..... \$2.50

- ROSE, J., M.E. Key to Engines and Engine-running.** A Practical Treatise upon the Management of Steam-engines and Boilers for the use of those who desire to pass an examination to take charge of an engine or boiler. With numerous illustrations, and Instructions upon Engineers' Calculations, Indicators, Diagrams, Engine Adjustments and other Valuable Information necessary for Engineers and Firemen. 12mo. cloth. Illus.. \$2 50
- ROWAN, F. J. The Practical Physics of the Modern Steam-boiler.** With an Introduction by Prof R. H. Thurston. With numerous illustrations and diagrams. 8vo, cloth, illustrated. \$7 50
- SABINE, R. History and Progress of the Electric Telegraph.** With descriptions of some of the apparatus. *Second Edition, with additions*. 12mo cloth .. \$1.25
- SAELTZER, A. Treatise on Acoustics in Connection with Ventilation.** 12mo. cloth. \$1.00
- SALOMONS, Sir D., M.A. Electric-light Installations.** A Practical Handbook. With numerous illustrations.. Vol. I., The Management of Accumulators. *Ninth Edition, revised and mostly rewritten.* 12mo cloth. \$1.50
Vol. II. *Seventh Edition, revised and enlarged.* Apparatus. 296 illustrations. 12mo, cloth. \$2.25
Vol. III. *Seventh Edition revised and enlarged.* Applications. 12mo, cloth. \$1.50
- SANFORD, P. G. Nitro-explosives. A Practical Treatise** concerning the Properties, Manufacture and Analysis of Nitrated Substances, including the Fulminates, Smokeless Powders and Celluloid. 8vo, cloth, 270 pages. \$3.00
- SAUNDERS, C. H. Handbook of Practical Mechanics** for use in the Shop and Draughting-room; containing Tables, Rules and Formulæ, and Solutions of Practical Problems by Simple and Quick Methods. 16mo, limp cloth. \$1.00
- SAUNNIER, C. Watchmaker's Handbook. A Workshop** Companion for those engaged in Watchmaking and allied Mechanical Arts. Translated by J. Tripplin and E. Rigg. *Second Edition, revised, with appendix.* 12mo, cloth. \$3.50
- SCHELLEN, H., Dr. Magneto-electric and Dynamo-electric Machines:** their Construction and Practical Application to Electric Lighting, and the Transmission of Power. Translated from the *third German edition* by N. S. Keith and Percy Neymann, Ph.D. With very large additions and notes relating to American Machines, by N. S. Keith. Vol. 1, with 353 illustrations. *Second Edition.* 8vo, cloth \$5.00

SCHERER, R. Casein: its Preparation and Technical Utilization. Translated from the German. 8vo, cloth, illustrated.*net*, \$3.00

SCHMALL, C. N. First Course in Analytical Geometry, Plane and Solid, with Numerous Examples. Containing figures and diagrams. 12mo, cloth, illustrated.*net*, \$1.75

SCHMALL, C. N., and SHACK, S. M. Elements of Plane Geometry. An Elementary Treatise. With many examples and diagrams. 12mo, half leather, illustrated.*net*, \$1.25

SCHMEER, LOUIS. Flow of Water: A New Theory of the Motion of Water under Pressure, and in Open Conduits. 8vo, cloth, illustrated.*In Press.*

SCHUMANN, F. A Manual of Heating and Ventilation in its Practical Application, for the use of Engineers and Architects. Embracing a Series of Tables and Formulæ for Dimensions of Heating, Flow and Return Pipes for Steam and Hot-water Boilers, Flues, etc. 12mo, illustrated, full roan. \$1.50

SCHWEIZER, V. Distillation of Resins, Resinate Lakes and Pigments; Carbon Pigments and Pigments for Typewriting Machines, Manifolders, etc. A description of the proper methods of distilling resin-oils, the manufacture of resins, resin-varnishes, resin-pigments and enamel paints, the preparation of all kinds of carbon pigments, and printers' ink, lithographic inks and chalks, and also inks for typewriters, manifolders, and rubber stamps. With tables and 68 figures and diagrams. 8vo, cloth, illustrated.*net*, \$3.50

SCIENCE SERIES, The Van Nostrand. (Follows end of this list.)

SCRIBNER, J. M. Engineers' and Mechanics' Companion. Comprising United States Weights and Measures, Mensuration of Superfices and Solids, Tables of Squares and Cubes, Square and Cube Roots, Circumference and Areas of Circles, the Mechanical Powers, Centres of Gravity, Gravitation of Bodies, Pendulums, Specific Gravity of Bodies, Strength, Weight and Crush of Materials, Water-wheels, Hydrostatics, Hydraulics, Statics, Centres of Percussion and Gyration, Friction Heat, Tables of the Weight of Metals, Scantling, etc., Steam and Steam-engine. *Twenty-first Edition, revised.* 16mo, full morocco. \$1.50

SEATON, A. E. *A Manual of Marine Engineering.* Comprising the Designing, Construction and Working of Marine Machinery. With numerous tables and illustrations reduced from Working Drawings. *Fifteenth Edition*, revised throughout, with an additional chapter on Water-tube Boilers. 8vo, cloth. \$6.00

— and **ROUNTHWAITE, H. M.** *A Pocket-book of Marine Engineering Rules and Tables.* For the use of Marine Engineers and Naval Architects, Designers, Draughtsmen, Superintendents and all engaged in the design and construction of Marine Machinery, Naval and Mercantile. *Seventh Edition*, revised and enlarged. Pocket size. Leather, with diagrams. \$3.00

SEIDELL, A. *Handbook of Solubilities.* 12mo, cloth.
In Press.

SEVER, G. F., Prof. *Electrical Engineering Experiments and Tests on Direct-current Machinery.* With diagrams and figures. 8vo pamphlet, illustrated. *net*, \$1.00

— and **TOWNSEND, F.** *Laboratory and Factory Tests in Electrical Engineering.* *Second Edition.* 8vo, cloth, illustrated. *net*, \$2.50

SEWALL, C. H. *Wireless Telegraphy.* With diagrams and engravings. *Second Edition, corrected.* 8vo, cloth, illustrated. *net*, \$2.00

— *Lessons in Telegraphy.* For use as a text-book in schools and colleges, or for individual students. Illustrated. 12mo, cloth. \$1.00

SEWELL, T. *Elements of Electrical Engineering.* A First Year's Course for Students. *Second Edition, revised*, with additional chapters on Alternating-current Working and Appendix of Questions and Answers. With many diagrams, tables and examples. 8vo, cloth, illustrated, 432 pages. *net*, \$3.00

SEXTON, A. H. *Fuel and Refractory Materials.* 8vo, cloth. \$2.00

— *Chemistry of the Materials of Engineering.* A Handbook for Engineering Students. With tables, diagrams and illustrations. 12mo, cloth, illustrated. \$2.50

SEYMOUR, A. *Practical Lithography.* With figures and engravings. 8vo, cloth, illustrated. *net*, \$2.50

SHAW, S. *The History of the Staffordshire Potteries, and the Rise and Progress of the Manufacture of Pottery and Porcelain; with references to genuine specimens, and notices of eminent potters. A re-issue of the original work published in 1829.* 8vo, cloth, illustrated. *net*, \$3.00

— **Chemistry of the Several Natural and Artificial Heterogeneous Compounds used in Manufacturing Porcelain, Glass and Pottery.** Re-issued in its original form, published in 1837. 8vo, cloth. *net*, \$5.00

SHELDON, S., Ph.D., and MASON, H., B.S. *Dynamo-electric Machinery: its Construction, Design and Operation, Direct-current Machines. Fifth Edition, revised.* 8vo, cloth, illustrated. *net*, \$2.50

— **Alternating-current Machines: being the second volume of the author's "Dynamo-electric Machinery: its Construction, Design and Operation." With many diagrams and figures. (Binding uniform with volume I.) Fourth Edition.** 8vo, cloth, illustrated. *net*, \$2.50

SHIELDS, J. E. *Notes on Engineering Construction.* Embracing Discussions of the Principles involved, and Descriptions of the Material employed in Tunneling, Bridging, Canal and Road Building, etc. 12mo, cloth. \$1.50

SHOCK, W. H. *Steam Boilers: their Design, Construction and Management.* 4to, half morocco. \$15.00

SHREVE, S. H. *A Treatise on the Strength of Bridges and Roofs.* Comprising the determination of algebraic formulas for strains in Horizontal, Inclined or Rafter, Triangular, Bow-string, Lenticular and other Trusses, from fixed and moving loads, with practical applications and examples, for the use of Students and Engineers. 87 woodcut illustrations. *Fourth Edition.* 8vo, cloth. \$3.50

SHUNK, W. F. *The Field Engineer. A Handy Book of practice in the Survey, Location and Track-work of Railroads, containing a large collection of Rules and Tables, original and selected, applicable to both the Standard and Narrow Gauge, and prepared with special reference to the wants of the young Engineer. Sixteenth Edition, revised and enlarged. With addenda* 12mo, morocco, tucks. \$2.50

- SIMMS, F. W.** *A Treatise on the Principles and Practice of Leveling.* Showing its application to purposes of Railway Engineering, and the Construction of Roads, etc. Revised and corrected, with the addition of Mr. Laws' Practical Examples for setting out Railway Curves. Illustrated. 8vo, cloth..... \$2.50
- **Practical Tunneling.** Fourth Edition, Revised and greatly extended. With additional chapters illustrating recent practice by D. Kinnear Clark. With 36 plates and other illustrations. Imperial 8vo, cloth..... \$8.00
- SIMPSON, G.** *The Naval Constructor. A Vade Mecum of Ship Design,* for Students, Naval Architects, Ship Builders and Owners, Marine Superintendents, Engineers and Draughtsmen. 12mo, morocco, illustrated, 500 pages. net, \$5.00
- SLATER, J. W.** *Sewage Treatment, Purification and Utilization.* A Practical Manual for the Use of Corporations, Local Boards, Medical Officers of Health, Inspectors of Nuisances, Chemists, Manufacturers, Riparian Owners, Engineers and Rate-payers. 12mo, cloth..... \$2.25
- SMITH, F. E.** *Handbook for Mechanics.* 12mo, cloth, illustrated.....*In Press.*
- **Mechanics for Practical Men.** 8vo, cloth, about 400 pp., illustrated.....*In Press.*
- **I. W., C.E.** *The Theory of Deflections and of Latitudes and Departures.* With special applications to Curvilinear Surveys, for Alignments of Railway Tracks. Illustrated. 16mo, morocco, tucks..... \$3.00
- **J. C.** *Manufacture of Paint. A Practical Handbook* for Paint Manufacturers, Merchants and Painters With 60 illustrations and one large diagram. 8vo, cloth.....net, \$3.00
- SNELL, A. T.** *Electric Motive Power: The Transmission and Distribution of Electric Power by Continuous and Alternate Currents.* With a Section on the Applications of Electricity to Mining Work. *Second Edition.* 8vo, cloth, illustrated..net, \$4.00
- SNOW, W. G., and NOLAN, T.** *Ventilation of Buildings.* 16mo, cloth. (Van Nostrand's Science Series.)..... \$0.50
- SODDY, F.** *Radio-Activity: An elementary treatise* from the standpoint of the disintegration theory. With 40 figures and diagrams. 8vo, cloth, illustrated.....net, \$3.00

- SOXHLET, D. H.** *Art of Dyeing and Staining Marble, Artificial Stone, Bone, Horn, Ivory and Wood, and of imitating all sorts of Wood. A practical Handbook for the use of Joiners, Turners, Manufacturers of Fancy Goods, Stick and Umbrella Makers, Comb Makers, etc. Translated from the German by Arthur Morris and Herbert Robson, B.Sc. 8vo, cloth, 170 pages. net, \$2.50*
- SPANG, H. W.** *A Practical Treatise on Lightning Protection. With figures and diagrams. 12mo, cloth. \$1.00*
- SPEYERS, C. L.** *Text-book of Physical Chemistry. 8vo, cloth. \$2.25*
- STAHL, A. W., and WOODS, A. T.** *Elementary Mechanism. A Text-book for Students of Mechanical Engineering. Fifteenth Edition. 12mo, cloth. \$2.00*
- STALEY, C., and PIERSON, G. S.** *The Separate System of Sewerage: its Theory and Construction. Third Edition, revised and enlarged. With chapter on Sewage Disposal. With maps, plates and illustrations. 8vo, cloth. \$3.00*
- STANDAGE, H. C.** *Leatherworkers' Manual: being a Compendium of Practical Recipes and Working Formulæ for Curriers, Boot-makers, Leather Dressers, Blacking Manufacturers, Saddlers, Fancy Leather Workers, and all persons engaged in the manipulation of leather. 8vo, cloth. net, \$3.50*
- *Sealing Waxes, Wafers, and Other Adhesives. For the Household, Office, Workshop and Factory. 8vo, cloth, 96 pages. net, \$2.00*
- STEWART, R. W.** *Text-book of Heat. Illustrated. 8vo, cloth. \$1.00*
- *Text-book of Magnetism and Electricity. 160 Illustrations and numerous examples. 12mo, cloth. \$1.00*
- STILES, A.** *Tables for Field Engineers. Designed for Use in the Field. Tables containing all the Functions of a One Degree Curve, from which a corresponding one can be found for any required Degree. Also, Tables of Natural Sines and Tangents. 12mo, morocco, tucks. \$2.00*

STILLMAN, P. Steam-engine Indicator and the Improved Manometer Steam and Vacuum Gauges; their Utility and Application. *New edition.* 12mo, flexible cloth..... \$1.00

STODOLA, Dr. A. Steam Turbines. With an appendix on Gas Turbines, and the future of Heat Engines. Authorized translation by Dr. Louis C. Loewenstein (Lehigh University). With 241 cuts and 3 lithographed tables. 8vo, cloth, illustrated. *net*, \$4.50

STONE, R., Gen'l. New Roads and Road Laws in the United States. 200 pages, with numerous illustrations. 12mo, cloth..... \$1.00

STONE, B. D. The Theory of Stresses in Girders and Similar Structures. With Observations on the Application of Theory to Practice, and Tables of Strength and other Properties of Materials. *New revised edition*, with numerous additions on Graphic Statics, Pillars, Steel, Wind Pressure, Oscillating Stresses, Working Loads, Riveting, Strength and Tests of Materials. 777 pages, 143 illus. and 5 folding-plates. 8vo, cloth.... \$12.50

SUFFLING, E. R. Treatise on the Art of Glass Painting. Prefaced with a Review of Ancient Glass. With engravings and colored plates. 8vo, cloth..... *net*, \$3.50

SWEET, S. H. Special Report on Coal, Showing its Distribution, Classification, and Costs delivered over Different Routes to Various Points in the State of New York and the Principal Cities on the Atlantic Coast. With maps. 8vo, cloth.... \$3.00

SWOOPE, C. W. Practical Lessons in Electricity: Principles, Experiments, and Arithmetical Problems. An Elementary Text-book. With numerous tables, formulæ, and two large instruction plates. 8vo, cloth, illustrated. *Seventh Edition.* *net*, \$2.00

TAILFER, L. Practical Treatise on the Bleaching of Linen and Cotton Yarn and Fabrics. With tables and diagrams. Translated from the French by John Geddes McIntosh. 8vo, cloth, illustrated..... *net*, \$5.00

TEMPLETON, W. The Practical Mechanic's Workshop Companion. Comprising a great variety of the most useful rules and formulæ in Mechanical Science, with numerous tables of practical data and calculated results facilitating mechanical operations. Revised and enlarged by W. S. Hutton. 12mo, morocco..... \$2.00

THOM, C., and JONES, W. H. *Telegraphic Connections: embracing Recent Methods in Quadruplex Telegraphy.* 20 full-page plates, some colored. Oblong, 8vo, cloth..... \$1.50

THOMAS, C. W. *Paper-makers' Handbook. A Practical Treatise.* Illustrated. *In Press.*

THOMPSON, A. B. *Oil Fields of Russia and the Russian Petroleum Industry. A Practical Handbook on the Exploration, Exploitation, and Management of Russian Oil Properties, including Notes on the Origin of Petroleum in Russia, a Description of the Theory and Practice of Liquid Fuel, and a Translation of the Rules and Regulations concerning Russian Oil Properties. With numerous illustrations and photographic plates and a map of the Balakhany-Saboontchy-Romany Oil Field.* 8vo, cloth, illustrated *net*, \$7.50

THOMPSON, E. P., M.E. *How to Make Inventions; or, Inventing as a Science and an Art. A Practical Guide for Inventors.* *Second Edition.* 8vo, boards..... \$0.50

— **Roentgen Rays and Phenomena of the Anode and Cathode.** Principles, Applications, and Theories. For Students, Teachers, Physicians, Photographers, Electricians and others. Assisted by Louis M. Pignolet, N. D. C. Hodges and Ludwig Gutmann, E.E. With a chapter on Generalizations, Arguments, Theories, Kindred Radiations and Phenomena. By Professor Wm. Anthony. 50 diagrams, 40 half-tones. 8vo, cloth..... \$1.00

THOMPSON, W. P. *Handbook of Patent Law of All Countries.* *Thirteenth Edition, completely revised,* March, 1905. 16mo, cloth..... \$1.50

THORNLEY, T. *Cotton Combing Machines.* With Numerous tables, engravings and diagrams. 8vo, cloth, illustrated. 343 pages. *net*, \$3.00

THURSO, J. W. *Modern Turbine Practice and Water-Power Plants.* With eighty-eight figures and diagrams. 8vo, cloth, illustrated..... *net*, \$4.00

TOCH, M. *Chemistry and Technology of Mixed Paints.* 8vo, cloth..... *In Press.*

- TODD, J., and WHALL, W. B. Practical Seamanship** for Use in the Merchant Service: including all ordinary subjects; also Steam Seamanship, Wreck Lifting, Avoiding Collision. Wire Splicing, Displacement and everything necessary to be known by seamen of the present day. *Fifth Edition*, with 247 illustrations and diagrams. 8vo, cloth..... *net*, \$7.50
- TOMPKINS, A. E. Text-book of Marine Engineering.** *Second Edition, entirely rewritten, rearranged, and enlarged.* With over 250 figures, diagrams, and full-page plates. 8vo, cloth, illustrated. *net*, \$6.00
- TOOTHED GEARING. A Practical Handbook for Offices and Workshops.** By a Foreman Patternmaker. 184 illustrations. 12mo, cloth..... \$2.25
- TRATMAN, E. E. R. Railway Track and Track-work.** With over 200 illustrations. 8vo, cloth..... \$3.00
- TRAVERSE TABLE, Showing Latitude and Departure** for each Quarter Degree of the Quadrant, and for Distances from 1 to 100, to which is appended a Table of Natural Sines and Tangents for each five minutes of the Quadrant. (Reprinted from Scribner's Pocket Table Book.) *Van Nostrand's Science Series.* 16mo, cloth. \$0.50
Morocco..... \$1.00
- TRINKS, W., and HOUSUM, C. Shaft Governors.** 16mo, cloth, illustrated. (Van Nostrand's Science Series.)..... \$0.50
- TUCKER, J. H., Dr. A Manual of Sugar Analysis,** including the Applications in General of Analytical Methods to the Sugar Industry. With an Introduction on the Chemistry of Cane-sugar, Dextrose, Levulose, and Milk-sugar. *Sixth Edition.* 8vo, cloth, illustrated. \$3.50
- TUMLIRZ, O., Dr. Potential and its Application to the** Explanation of Electrical Phenomena, Popularly Treated. Translated from the German by D. Robertson. 12mo, cloth, ill. \$1.25
- TUNNER, P. A. Treatise on Roll-turning for the Manu-** facture of Iron. Translated and adapted by John B. Pearse, of the Pennsylvania Steel Works, with numerous engravings, woodcuts. 8vo, cloth, with folio atlas of plates..... \$10.00
- TURBAYNE, A. A. Alphabets and Numerals.** With 27 plates. 4to, boards..... \$2.00

UNDERHILL, C. R. *The Electro-magnet. New and revised edition.* 8vo, cloth, illustrated. *net*, \$1.50

URQUHART, J. W. *Electric Light Fitting. Embodying Practical Notes on Installation Management. A Handbook for Working Electrical Engineers. With numerous illustrations.* 12mo, cloth. \$2.00

— **Electro-plating.** *A Practical Handbook on the Deposition of Copper, Silver, Nickel, Gold, Brass, Aluminium, Platinum, etc. Fourth Edition.* 12mo. \$2.00

— **Electrotyping.** *A Practical Manual Forming a New and Systematic Guide to the Reproduction and Multiplication of Printing Surfaces, etc.* 12mo. \$2.00

— **Electric Ship Lighting.** *A Handbook on the Practical Fitting and Running of Ship's Electrical Plant. For the Use of Ship Owners and Builders, Marine Electricians and Sea-going Engineers-in-Charge.* Illustrated. 12mo, cloth. \$3.00

UNIVERSAL TELEGRAPH CIPHER CODE. *Arranged for General Correspondence.* 12mo, cloth. \$1.00

VAN NOSTRAND'S Chemical Annual, based on Biedermann's "Chemiker Kalender." Edited by Prof. J. C. Olsen, with the co-operation of Eminent Chemists. First year of issue 1906. 12mo, cloth, illustrated. *In Press.*

— **Engineering Magazine.** *Complete Sets, 1869 to 1886 inclusive.* 35 vols., in cloth. \$60.00
 " " in half morocco. \$100.00

— **Year Book of Mechanical Engineering Data.** *With many tables and diagrams. (First Year of issue 1906.)* *In Press.*

VAN WAGENEN, T. F. *Manual of Hydraulic Mining. For the Use of the Practical Miner. Revised and enlarged edition.* 18mo, cloth. \$1.00

VILLON, A. M. *Practical Treatise on the Leather Industry. With many tables and illustrations and a copious index. A translation of Villon's "Traite Pratique de la Fabrication des Cuirs et du Travail des Peaux," by Frank T. Addyman, B.Sc.* 8vo, cloth, illustrated. *net*, \$10.00

VINCENT, C. *Ammonia and its Compounds: their Manufacture and Uses.* Translated from the French by M. J. Salter. 8vo, cloth, illustrated. *net*, \$2.00

VOLK, C. *Haulage and Winding Appliances Used in Mines.* With plates and engravings. Translated from the German. 8vo, cloth, illustrated. *net*, \$4.00

VON GEORGIEVICS, G. *Chemical Technology of Textile Fibres: their Origin, Structure, Preparation, Washing, Bleaching, Dyeing, Printing, and Dressing.* Translated from the German by Charles Salter. With many diagrams and figures. 8vo, cloth, illustrated. 306 pages. *net*, \$4.50
Contents.—The Textile Fibres; Washing, Bleaching, and Carbonizing; Mordants and Mordanting; Dyeing, Printing, Dressing and Finishing; Index.

— **Chemistry of Dyestuffs.** Translated from the Second German edition by Chas. Salter. 8vo, cloth, 412 pages. *net*, \$4.50

WABNER, R. *Ventilation in Mines.* Translated from the German by Charles Salter. With plates and engravings. 8vo, cloth, illustrated, 240 pages. *net*, \$4.50

WADE, E. J. *Secondary Batteries: their Theory, Construction and Use.* With innumerable diagrams and figures. 8vo, cloth, illustrated, 492 pages. *net*, \$4.00

WALKER, F., C.E. *Aërial Navigation. A Practical Handbook on the Construction of Dirigible Balloons, Aërostats, Aëroplanes and Aëromotors.* With diagrams, tables and illustrations. 8vo, cloth, illustrated, 151 pages. *net*, \$3.00

WALKER, S. F. *Electrical Engineering in Our Homes and Workshops. A Practical Treatise on Auxiliary Electrical Apparatus. Third Edition, revised, with numerous illustrations.* 8vo, cloth. \$2.00

— **Electric Lighting for Marine Engineers, or How to Light a Ship by the Electric Light and How to Keep the Apparatus in Order.** *Second Edition.* 103 illus., 8vo, cloth. \$2.00

WALKER, W. H. *Screw Propulsion. Notes on Screw Propulsion; its Rise and History.* 8vo, cloth. \$0.75

WALLING, B. T., Lieut. Com. U.S.N., and MARTIN, JULIUS. *Electrical Installations of the United States Navy. With many diagrams and engravings.* 8vo, cloth, illustrated. *In Press.*

- WALLIS TAYLER, A. J. Bearings and Lubrication. A Handbook for Every user of Machinery. Fully illustrated. 8vo, cloth. \$1.50**
- **Modern Cycles, a Practical Handbook on Their Construction and Repair. With 300 illustrations. 8vo, cloth. \$4.00**
- **Motor Cars, or Power Carriages for Common Roads. With numerous illustrations. 8vo, cloth. \$1.80**
- **Motor Vehicles for Business Purposes. 8vo, cloth, illustrated. net. \$3.50.**
- **Refrigerating and Ice-making Machinery. A Descriptive Treatise for the use of persons employing refrigerating and ice-making installations, and others. 8vo, cloth, illustrated. \$3.00**
- **Refrigeration and Cold Storage: being a Complete practical treatise on the art and science of refrigeration. 600 pages, 361 diagrams and figures. 8vo, cloth net, \$4.50**
- **Sugar Machinery. A Descriptive Treatise, devoted to the Machinery and Apparatus used in the Manufacture of Cane and Beet Sugars. 12mo, cloth, illustrated. \$2.00**
- WANKLYN, J. A. A Practical Treatise on the Examination of Milk and its Derivatives, Cream, Butter and Cheese. 12mo, cloth. \$1.00**
- **Water Analysis. A Practical Treatise on the Examination of Potable Water. Tenth Edition. 12mo, cloth.... \$2.00**
- WANSBROUGH, W. D. The A B C of the Differential Calculus. 12mo, cloth. \$1.50**
- WARD, J. H. Steam for the Million. A Popular Treatise on Steam, and its application to the Useful Arts, especially to Navigation. 8vo, cloth. \$1.00**
- WARING, G. E., Jr. Sewerage and Land Drainage. Illustrated with woodcuts in the text, and full-page and folding plates. New Edition. In Press.**
- **Modern Methods of Sewage Disposals for Towns, Public Institutions and Isolated Houses. Second Edition, revised and enlarged. 260 pages. Illustrated. Cloth..... \$2.00**

WARING, G. E., Jr. **How to Drain a House. Practical Information for Householders. Third Edition, enlarged.** 12mo. cloth..... \$1.25

WARREN, F. D. **Handbook on Reinforced Concrete.** 16mo, cloth, illustrated.....net, \$2.50

WATSON, E. P. **Small Engines and Boilers. A Manual of Concise and Specific Directions for the Construction of Small Steam-engines and Boilers of Modern Types from five Horse-power down to model sizes. Illustrated with Numerous Diagrams and Half-tone Cuts.** 12mo, cloth..... \$1.25

WATT, A. **Electro-plating and Electro-refining of Metals:** being a new edition of Alexander Watts' "Electro-Deposition." *Revised and largely rewritten by Arnold Philip, B.Sc. With numerous figures and engravings.* 8vo, cloth, illustrated, 680 pages..... net, \$4.50

— **Electro-metallurgy Practically Treated. Eleventh Edition, considerably enlarged.** 12mo, cloth..... \$1.00

— **The Art of Soap-making. A Practical Handbook of the Manufacture of Hard and Soft Soaps, Toilet Soaps, etc. Including many New Processes, and a Chapter on the Recovery of Glycerine from Waste Lyes. With illustrations. Fifth Edition, revised and enlarged.** 8vo, cloth..... \$3.00

— **The Art of Leather Manufacture: being a Practical Handbook, in which the Operations of Tanning, Currying and Leather Dressing are Fully Described, and the Principles of Tanning Explained, and many Recent Processes Introduced. With numerous illustrations. New Edition.** In Press.

WEALE, J. **A Dictionary of Terms Used in Architecture, Building, Engineering, Mining, Metallurgy, Archæology, the Fine Arts, etc., with explanatory observations connected with applied Science and Art. Fifth Edition, revised and corrected.** 12mo, cloth..... \$2.50

WEBB, H. L. **A Practical Guide to the Testing of Insulated Wires and Cables. Illustrated.** 12mo, cloth..... \$1.00

— **The Telephone Handbook. 128 Illustrations. 146 pages.** 16mo, cloth..... \$1.00

WEEKES, R. W. The Design of Alternate Current Transformers. Illustrated. 12mo, cloth. \$1.00

WEISBACH, J. A Manual of Theoretical Mechanics. *Ninth American edition.* Translated from the fourth augmented and improved German edition, with an Introduction to the Calculus by Eckley B. Coxe, A.M., Mining Engineer. 1,100 pages and 902 woodcut illustrations. 8vo, cloth. \$6.00
Sheep. \$7.50

— and **HERRMANN, G.** Mechanics of Air Machinery. Authorized translation, with an appendix on American practice by A. Trowbridge. With figures, diagrams, and folding plates. 8vo, cloth, illustrated. *net*, \$3.75

WESTON, E. B. Tables Showing Loss of Head Due to Friction of Water in Pipes. *Second Edition.* 12mo, cloth. . \$1.50

WEYMOUTH, F. M. Drum Armatures and Commutators. (Theory and Practice.) A complete Treatise on the Theory and Construction of Drum Winding, and of commutators for closed-coil armatures, together with a full résumé of some of the principal points involved in their design, and an exposition of armature reactions and sparking. 8vo, cloth. \$3.00

WHEELER, J. B., Prof. Art of War. A Course of Instruction in the Elements of the Art and Science of War, for the Use of the Cadets of the United States Military Academy, West Point, N. Y. 12mo, cloth. \$1.75

— **Field Fortifications.** The Elements of Field Fortifications, for the Use of the Cadets of the United States Military Academy, West Point, N. Y. 12mo, cloth. \$1.75

WHIPPLE, S., C.E. An Elementary and Practical Treatise on Bridge Building. 8vo, cloth. \$3.00

WHITE, W. H., K.C.B. A Manual of Naval Architecture, for use of Officers of the Royal Navy, Officers of the Mercantile Marine, Yachtsmen, Shipowners and Shipbuilders. Containing many figures, diagrams and tables. Thick, 8vo, cloth, illustrated. \$9.00

WILKINSON, H. D. Submarine Cable-laying, Repairing, and Testing. 8vo, cloth. *New Edition.* *In Press.*

WILLIAMSON, R. S. *On the Use of the Barometer on Surveys and Reconnoissances.* Part I. Meteorology in its Connection with Hypsometry. Part II. Barometric Hypsometry. With illustrative tables and engravings. 4to, cloth.... \$15.00

— **Practical Tables in Meteorology and Hypsometry,** in connection with the use of the Barometer. 4to, cloth..... \$2.50

WILSON, G. *Inorganic Chemistry, with New Notation.* Revised and enlarged by H. G. Madan. *New edition.* 12mo, cloth..... \$2.00

WILLSON, F. N. *Theoretical and Practical Graphics.* An Educational Course on the Theory and Practical Applications of Descriptive Geometry and Mechanical Drawing. Prepared for students in General Science, Engraving, or Architecture. *Third Edition, revised.* 4to, cloth, illustrated. net, \$4.00

— **Note-taking, Dimensioning and Lettering.** 4to, Cloth, illustrated. net, \$1.25

— **Third Angle Method of Making Working Drawings.** 4to, cloth, illustrated. net, \$1.25

— **Some Mathematical Curves, and Their Graphical Construction.** 4to, cloth, illustrated. net, \$1.50

— **Practical Engineering, Drawing, and Third Angle Projection.** 4to, cloth, illustrated. net, \$2.80

— **Shades, Shadows, and Linear Perspective.** 4to, Cloth, illustrated. net, \$1.00

— **Descriptive Geometry—Pure and Applied, with a chapter on Higher Plane Curves, and the Helix.** 4to, cloth illustrated. net, \$3.00

WINKLER, C., and LUNGE, G. *Handbook of Technical Gas-Analysis.* With figures and diagrams. *Second English edition.* Translated from the third greatly enlarged German edition, with some additions by George Lunge, Ph.D. 8vo, cloth, illustrated, 190 pages. \$4.00

WOODBURY, D. V. Treatise on the Various Elements of Stability in the Well-proportioned Arch. With numerous tables of the Ultimate and Actual Thrust. 8vo, half morocco. Illustrated..... \$4.00

WRIGHT, A. C. Analysis of Oils and Allied Substances. 8vo, cloth, illustrated, 241 pages..... *net*, \$3.50

— **Simple Method for Testing Painters' Materials.** 8vo, cloth, 160 pages..... *net*, \$2.50

WRIGHT, T. W., Prof. (Union College.) Elements of Mechanics; including Kinematics, Kinetics and Statics. With applications. *Third Edition, revised and enlarged.* 8vo, cloth... \$2.50

— **and HAYFORD, J. F.** Adjustment of Observations by the Method of Least Squares, with applications to Geodetic Work. *Second Edition, rewritten.* 8vo, cloth, illustrated. *net*, \$3.00

YOUNG, J. E. Electrical Testing for Telegraph Engineers. With Appendices consisting of Tables. 8vo, cloth, illus... \$4.00

YOUNG SEAMAN'S MANUAL. Compiled from Various Authorities, and Illustrated with Numerous Original and Select Designs, for the Use of the United States Training Ships and the Marine Schools. 8vo, half roan..... \$3.00

ZEUNER, A., Dr. Technical Thermodynamics. Translated from the German, by Prof. J. F. Klein, Lehigh University. 8vo, cloth, illustrated..... *In Press.*

ZIMMER, G. F. Mechanical Handling of Material. Being a treatise on the handling of material, such as coal, ore, timber, etc., by automatic and semi-automatic machinery, together with the various accessories used in the manipulation of such plant, also dealing fully with the handling, storing, and warehousing of grain. With 542 figures, diagrams, full-page and folding plates. Royal 8vo, cloth, illustrated..... *net*, \$10.00

ZIPSER, J. Textile Raw Materials, and Their Conversion into Yarns. The study of the Raw Materials and the Technology of the Spinning Process. A Text-book for Textile, Trade and higher Technical Schools, as also for self-instruction. Based upon the ordinary syllabus and curriculum of the Imperial and Royal Weaving Schools. Translated from the German by Chas. Salter. 8vo, cloth, illustrated..... *net*, \$5.00

Catalogue of the Van Nostrand Science Series.

THEY are put up in a uniform, neat, and attractive form. 18mo, boards. Price 50 cents per volume. The subjects are of an eminently scientific character and embrace a wide range of topics, and are amply illustrated when the subject demands.

- No. 1. CHIMNEYS FOR FURNACES AND STEAM BOILERS.** By R. Armstrong, C.E. Third American Edition. Revised and partly rewritten, with an Appendix on "Theory of Chimney Draught," by F. E. Idell, M.E.
- No. 2. STEAM-BOILER EXPLOSIONS.** By Zerah Colburn. New Edition, revised by Prof. R. H. Thurston.
- No. 3. PRACTICAL DESIGNING OF RETAINING-WALLS.** Fourth edition, by Prof. W. Cain.
- No. 4. PROPORTIONS OF PINS USED IN BRIDGES.** By Charles E. Bender, C.E. Second edition, with Appendix.
- No. 5. VENTILATION OF BUILDINGS.** By Wm. G. Snow, S.B., and Thos. Nolan, A.M.
- No. 6. ON THE DESIGNING AND CONSTRUCTION OF STORAGE Reservoirs.** By Arthur Jacob, B.A. Third American edition, revised, with additions by E. Sherman Gould.
- No. 7. SURCHARGED AND DIFFERENT FORMS OF RETAINING-walls.** By James S. Tate, C.E.
- No. 8. A TREATISE ON THE COMPOUND STEAM-ENGINE.** By John Turnbull, Jr. 2nd edition, revised by Prof. S. W. Robinson.
- No. 9. A TREATISE ON FUEL.** By Arthur V. Abbott, C.E. Founded on the original treatise of C. William Siemens, D.C.L. Third ed.
- No. 10. COMPOUND ENGINES.** Translated from the French of A. Mallet. Second edition, revised with results of American Practice, by Richard H. Buel, C.E.
- No. 11. THEORY OF ARCHES.** By Prof. W. Allan.
- No. 12. THEORY OF VOUSSOIR ARCHES.** By Prof. Wm. Cain. Third edition, revised and enlarged.
- No. 13. GASES MET WITH IN COAL MINES.** By J. J. Atkinson. Third edition, revised and enlarged, to which is added The Action of Coal Dusts by Edward H. Williams, Jr.

D. VAN NOSTRAND CO.'S SCIENTIFIC PUBLICATIONS.

- No. 14. FRICTION OF AIR IN MINES.** By J. J. Atkinson. Second American edition.
- No. 15. SKEW ARCHES.** By Prof. E. W. Hyde, C.E. Illustrated. Second edition.
- No. 16. GRAPHIC METHOD FOR SOLVING CERTAIN QUESTIONS in Arithmetic or Algebra.** By Prof. G. L. Vose. Second edition.
- No. 17. WATER AND WATER-SUPPLY.** By Prof. W. H. Corfield, of the University College, London. Second American edition.
- No. 18. SEWERAGE AND SEWAGE PURIFICATION.** By M. N. Baker, Associate Editor "Engineering News." Second edition, revised and enlarged.
- No. 19. STRENGTH OF BEAMS UNDER TRANSVERSE LOADS.** By Prof. W. Allan, author of "Theory of Arches." Second edition, revised.
- No. 20. BRIDGE AND TUNNEL CENTRES.** By John B. McMaster, C.E. Second edition.
- No. 21. SAFETY VALVES.** By Richard H. Buel, C.E. Third edition.
- No. 22. HIGH MASONRY DAMS.** By E. Sherman Gould, M. Am. Soc. C. E.
- No. 23. THE FATIGUE OF METALS UNDER REPEATED STRAINS.** With various Tables of Results and Experiments. From the German of Prof. Ludwig Spangenburg, with a Preface by S. H. Shreve, A.M.
- No. 24. A PRACTICAL TREATISE ON THE TEETH OF WHEELS.** By Prof. S. W. Robinson. 2nd edition, revised, with additions.
- No. 25. THEORY AND CALCULATION OF CANTILEVER BRIDGES.** By R. M. Wilcox.
- No. 26. PRACTICAL TREATISE ON THE PROPERTIES OF Continuous Bridges.** By Charles Bender, C.E.
- No. 27. BOILER INCRUSTATION AND CORROSION.** By F. J. Rowan. New edition. Revised and partly rewritten by F. E. Idell.
- No. 28. TRANSMISSION OF POWER BY WIRE ROPES.** By Albert W. Stahl, U.S.N. Second edition, revised.
- No. 29. STEAM INJECTORS, THEIR THEORY AND USE.** Translated from the French of M. Leon Pochet.
- No. 30. MAGNETISM OF IRON VESSELS AND TERRESTRIAL Magnetism.** By Prof. Fairman Rogers.

D. VAN NOSTRAND COMPANY'S

- No. 31. THE SANITARY CONDITION OF CITY AND COUNTRY Dwelling-houses.** By George E. Waring, Jr. Second edition, revised.
- No. 32. CABLE-MAKING FOR SUSPENSION BRIDGES.** By W. Hildenbrand, C.E.
- No. 33. MECHANICS OF VENTILATION.** By George W. Rafter, C.E. Second edition, revised.
- No. 34. FOUNDATIONS.** By Prof. Jules Gaudard, C.E. Translated from the French. Second edition.
- No. 35. THE ANEROID BAROMETER: ITS CONSTRUCTION AND Use.** Compiled by George W. Plympton. Ninth edition, revised and enlarged.
- No. 36. MATTER AND MOTION.** By J. Clerk Maxwell, M.A. Second American edition.
- No. 37. GEOGRAPHICAL SURVEYING: ITS USES, METHODS, and Results.** By Frank De Yeaux Carpenter, C.E.
- No. 38. MAXIMUM STRESSES IN FRAMED BRIDGES.** By Prof. William Cain, A.M., C.E. New and revised edition.
- No. 39. A HANDBOOK OF THE ELECTRO-MAGNETIC TELE-graph.** By A. E. Loring. Fourth edition, revised.
- No. 40. TRANSMISSION OF POWER BY COMPRESSED AIR.** By Robert Zahner, M.E. New edition, in press.
- No. 41. STRENGTH OF MATERIALS.** By William Kent, C.E., Assoc. Editor "Engineering News." Second edition.
- No. 42. THEORY OF STEEL-CONCRETE ARCHES, AND OF Vaulted Structures.** By Prof. Wm. Cain. Third edition, thoroughly revised.
- No. 43. WAVE AND VORTEX MOTION.** By Dr. Thomas Craig, of Johns Hopkins University.
- No. 44. TURBINE WHEELS.** By Prof. W. P. Trowbridge, Columbia College. Second edition. Revised.
- No. 45. THERMO-DYNAMICS.** By Prof. H. T. Eddy, University of Cincinnati. New edition, in press.
- No. 46. ICE-MAKING MACHINES.** From the French of M. Le Doux. Revised by Prof. J. E. Denton, D. S. Jacobus, and A. Riesenberger. Fifth edition, revised.
- No. 47. LINKAGES: THE DIFFERENT FORMS AND USES OF Articulated Links.** By J. D. C. De Roos.
- No. 48. THEORY OF SOLID AND BRACED ELASTIC ARCHES** By William Cain, C.E.
- No. 49. MOTION OF A SOLID IN A FLUID.** By Thomas Craig, Ph.D.

SCIENTIFIC PUBLICATIONS.

- No. 50. DWELLING-HOUSES: THEIR SANITARY CONSTRUCTION and Arrangements.** By Prof. W. H. Corfield.
- No. 51. THE TELESCOPE: OPTICAL PRINCIPLES INVOLVED IN the Construction of Refracting and Reflecting Telescopes, with a new chapter on the Evolution of the Modern Telescope, and a Bibliography to date.** With diagrams and folding plates. By Thomas Nolan. Second edition, revised and enlarged.
- No. 52. IMAGINARY QUANTITIES: THEIR GEOMETRICAL INTERPRETATION.** Translated from the French of M. Argand by Prof. A. S. Hardy.
- No. 53. INDUCTION COILS: HOW MADE AND HOW USED.** Eleventh American edition.
- No. 54. KINEMATICS OF MACHINERY.** By Prof. Alex. B. W. Kennedy. With an introduction by Prof. R. H. Thurston.
- No. 55. SEWER GASES: THEIR NATURE AND ORIGIN.** By A. de Varona. Second edition, revised and enlarged.
- No. 56. THE ACTUAL LATERAL PRESSURE OF EARTHWORK.** By Benj. Baker, M. Inst., C.E.
- No. 57. INCANDESCENT ELECTRIC LIGHTING.** A Practical Description of the Edison System. By L. H. Latimer. To which is added the Design and Operation of Incandescent Stations, by C. J. Field; and the Maximum Efficiency of Incandescent Lamps, by John W. Howell.
- No. 58. VENTILATION OF COAL MINES.** By W. Fairley, M.E., and Geo. J. André.
- No. 59. RAILROAD ECONOMICS; OR, NOTES WITH COMMENTS.** By S. W. Robinson, C.E.
- No. 60. STRENGTH OF WROUGHT-IRON BRIDGE MEMBERS.** By S. W. Robinson, C.E.
- No. 61. POTABLE WATER, AND METHODS OF DETECTING Impurities.** By M. N. Baker. Second ed., revised and enlarged.
- No. 62. THEORY OF THE GAS-ENGINE.** By Dougald Clerk. Third edition. With additional matter. Edited by F. E. Idell, M.E.
- No. 63. HOUSE-DRAINAGE AND SANITARY PLUMBING.** By W. P. Gerhard. Tenth edition.
- No. 64. ELECTRO-MAGNETS.** By A. N. Mansfield.
- No. 65. POCKET LOGARITHMS TO FOUR PLACES OF DECIMALS.** Including Logarithms of Numbers, etc.
- No. 66. DYNAMO-ELECTRIC MACHINERY.** By S. P. Thompson. With an Introduction by F. L. Pope. Third edition, revised.
- No. 67. HYDRAULIC TABLES FOR THE CALCULATION OF THE Discharge through Sewers, Pipes, and Conduits.** Based on "Kutter's Formula." By P. J. Flynn.

D. VAN NOSTRAND COMPANY'S

- No. 68. STEAM-HEATING.** By Robert Briggs. Third edition, revised, with additions by A. R. Wolff.
- No. 69. CHEMICAL PROBLEMS.** By Prof. J. C. Foye. Fourth edition, revised and enlarged.
- No. 70. EXPLOSIVE MATERIALS.** By Lieut. John P. Wisser.
- No. 71. DYNAMIC ELECTRICITY.** By John Hopkinson, J. A. Shoolbred, and R. E. Day.
- No. 72. TOPOGRAPHICAL SURVEYING.** By George J. Specht, Prof. A. S. Hardy, John B. McMaster, and H. F. Walling. Third edition, revised.
- No. 73. SYMBOLIC ALGEBRA; OR, THE ALGEBRA OF ALGEBRAIC NUMBERS.** By Prof. William Cain.
- No. 74. TESTING MACHINES: THEIR HISTORY, CONSTRUCTION and Use.** By Arthur V. Abbott.
- No. 75. RECENT PROGRESS IN DYNAMO-ELECTRIC MACHINES.** Being a Supplement to "Dynamo-electric Machinery." By Prof. Sylvanus P. Thompson.
- No. 76. MODERN REPRODUCTIVE GRAPHIC PROCESSES.** By Lieut. James S. Pettit, U.S.A.
- No. 77. STADIA SURVEYING.** The Theory of Stadia Measurements. By Arthur Winslow. Sixth edition.
- No. 78. THE STEAM-ENGINE INDICATOR AND ITS USE.** By W. B. Le Van.
- No. 79. THE FIGURE OF THE EARTH.** By Frank C. Roberts, C.E.
- No. 80. HEALTHY FOUNDATIONS FOR HOUSES.** By Glenn Brown.
- No. 81. WATER METERS: COMPARATIVE TESTS OF ACCURACY,** Delivery, etc. Distinctive features of the Worthington, Kennedy, Siemens, and Hesse meters. By Ross E. Browne.
- No. 82. THE PRESERVATION OF TIMBER BY THE USE OF ANTISEPTICS.** By Samuel Bagster Boulton, C.E.
- No. 83. MECHANICAL INTEGRATORS.** By Prof. Henry S. H. Shaw, C.E.
- No. 84. FLOW OF WATER IN OPEN CHANNELS, PIPES, CONDUITS, SEWERS, etc.** With Tables. By P. J. Flynn, C.E.
- No. 85. THE LUMINIFEROUS ÆTHER.** By Prof. De Volson Wood.
- No. 86. HANDBOOK OF MINERALOGY: DETERMINATION, DESCRIPTION, and Classification of Minerals Found in the United States.** By Prof. J. C. Foye. Fifth edition, revised.

SCIENTIFIC PUBLICATIONS.

- No. 87. TREATISE ON THE THEORY OF THE CONSTRUCTION of Helicoidal Oblique Arches.** By John L. Culley, C.E.
- No. 88. BEAMS AND GIRDERS.** Practical Formulas for their Resistance. By P. H. Philbrick.
- No. 89. MODERN GUN COTTON: ITS MANUFACTURE, PROPERTIES, and Analyses.** By Lieut. John P. Wisser, U.S.A.
- No. 90. ROTARY MOTION AS APPLIED TO THE GYROSCOPE.** By Major J. G. Barnard.
- No. 91. LEVELING: BAROMETRIC, TRIGONOMETRIC, AND Spirit.** By Prof. I. O. Baker. Second edition.
- No. 92. PETROLEUM: ITS PRODUCTION AND USE.** By Boverton Redwood, F.I.C., F.C.S.
- No. 93. RECENT PRACTICE IN THE SANITARY DRAINAGE OF Buildings.** With Memoranda on the Cost of Plumbing Work. Second edition, revised and enlarged. By William Paul Gerhard, C.E.
- No. 94. THE TREATMENT OF SEWAGE.** By Dr. C. Meymott Tidy.
- No. 95. PLATE-GIRDER CONSTRUCTION.** By Isami Hiroi, C.E. Fourth edition, revised.
- No. 96. ALTERNATE CURRENT MACHINERY.** By Gisbert Kapp, Assoc. M. Inst., C.E.
- No. 97. THE DISPOSAL OF HOUSEHOLD WASTES.** By W. Paul Gerhard, Sanitary Engineer.
- No. 98. PRACTICAL DYNAMO-BUILDING FOR AMATEURS. HOW to Wind for Any Output.** By Frederick Walker. Fully illustrated. Third edition.
- No. 99. TRIPLE-EXPANSION ENGINES AND ENGINE TRIALS.** By Prof. Osborne Reynolds. Edited with notes, etc., by F. E. Idell, M.E.
- No. 100. HOW TO BECOME AN ENGINEER; or, The Theoretical and Practical Training necessary in Fitting for the Duties of the Civil Engineer.** By Prof. Geo. W. Plympton.
- No. 101. THE SEXTANT, and Other Reflecting Mathematical Instruments.** With Practical Hints for their Adjustment and Use. By F. R. Brainard, U. S. Navy.
- No. 102. THE GALVANIC CIRCUIT INVESTIGATED MATHEMATICALLY.** By Dr. G. S. Ohm, Berlin, 1827. Translated by William Francis. With Preface and Notes by the Editor, Thomas D. Lockwood, M.I.E.E.

D. VAN NOSTRAND COMPANY'S

- No. 103. THE MICROSCOPICAL EXAMINATION OF POTABLE Water.** With Diagrams. By Geo. W. Rafter. Second edition.
- No. 104. VAN NOSTRAND'S TABLE-BOOK FOR CIVIL AND MECHANICAL ENGINEERS.** Compiled by Prof. Geo. W. Plympton.
- No. 105. DETERMINANTS.** An Introduction to the Study of, with Examples and Applications. By Prof. G. A. Miller.
- No. 106. COMPRESSED AIR.** Experiments upon the Transmission of Power by Compressed Air in Paris. (Popp's System.) By Prof. A. B. W. Kennedy. The Transmission and Distribution of Power from Central Stations by Compressed Air. By Prof. W. C. Unwin. Edited by F. E. Idell. Third edition.
- No. 107. A GRAPHICAL METHOD FOR SWING BRIDGES.** A Rational and Easy Graphical Analysis of the Stresses in Ordinary Swing Bridges. With an Introduction on the General Theory of Graphical Statics, with Folding Plates. By Benjamin F. La Rue.
- No. 108. SLIDE-VALVE DIAGRAMS.** A French Method for Constructing Slide-valve Diagrams. By Lloyd Bankson, B.S., Assistant Naval Constructor, U. S. Navy. 8 Folding Plates.
- No. 109. THE MEASUREMENT OF ELECTRIC CURRENTS.** Electrical Measuring Instruments. By James Swinburne. Meters for Electrical Energy. By C. H. Wordingham. Edited, with Preface, by T. Commerford Martin. With Folding Plate and Numerous Illustrations.
- No. 110. TRANSITION CURVES.** A Field-book for Engineers, Containing Rules and Tables for Laying out Transition Curves. By Walter G. Fox, C.E.
- No. 111. GAS-LIGHTING AND GAS-FITTING.** Specifications and Rules for Gas-piping. Notes on the Advantages of Gas for Cooking and Heating, and Useful Hints to Gas Consumers. Third edition. By Wm. Paul Gerhard, C.E.
- No. 112. A PRIMER ON THE CALCULUS.** By E. Sherman Gould, M. Am. Soc. C. E. Third edition, revised and enlarged.
- No. 113. PHYSICAL PROBLEMS and Their Solution.** By A. Bourgougnon, formerly Assistant at Bellevue Hospital. Second ed.
- No. 114. MANUAL OF THE SLIDE RULE.** By F. A. Halsey, of the "American Machinist." Third edition, corrected.
- No. 115. TRAVERSE TABLE.** Showing the Difference of Latitude and Departure for Distances Between 1 and 100 and for Angles to Quarter Degrees Between 1 Degree and 90 Degrees. (Reprinted from Scribner's Pocket Table Book.)

SCIENTIFIC PUBLICATIONS.

- No. 116. WORM AND SPIRAL GEARING.** Reprinted from "American Machinist." By F. A. Halsey. Second revised and enlarged edition.
- No. 117. PRACTICAL HYDROSTATICS, AND HYDROSTATIC FORMULAS.** With Numerous Illustrative Figures and Numerical Examples. By E. Sherman Gould.
- No. 118. TREATMENT OF SEPTIC SEWAGE,** with Diagrams and Figures. By Geo. W. Rafter.
- No. 119. LAY-OUT OF CORLISS VALVE GEARS.** With Folding Plates and Diagrams. By Sanford A. Moss, M.S., Ph.D. Reprinted from "The American Machinist," with revisions and additions. Second edition.
- No. 120. ART OF GENERATING GEAR TEETH.** By Howard A. Coombs. With Figures, Diagrams and Folding Plates. Reprinted from the "American Machinist."
- No. 121. ELEMENTS OF GAS ENGINE DESIGN.** Reprint of a Set of Notes accompanying a Course of Lectures delivered at Cornell University in 1902. By Sanford A. Moss. Illustrated.
- No. 122. SHAFT GOVERNORS.** By W. Trinks and C. Housum. Illustrated.
- No. 123. FURNACE DRAFT; ITS PRODUCTION BY MECHANICAL METHODS.** A Handy Reference Book, with figures and tables. By William Wallace Christie. Illustrated.